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PESTICIDES IN THE AQUATIC ENVIRONMENT

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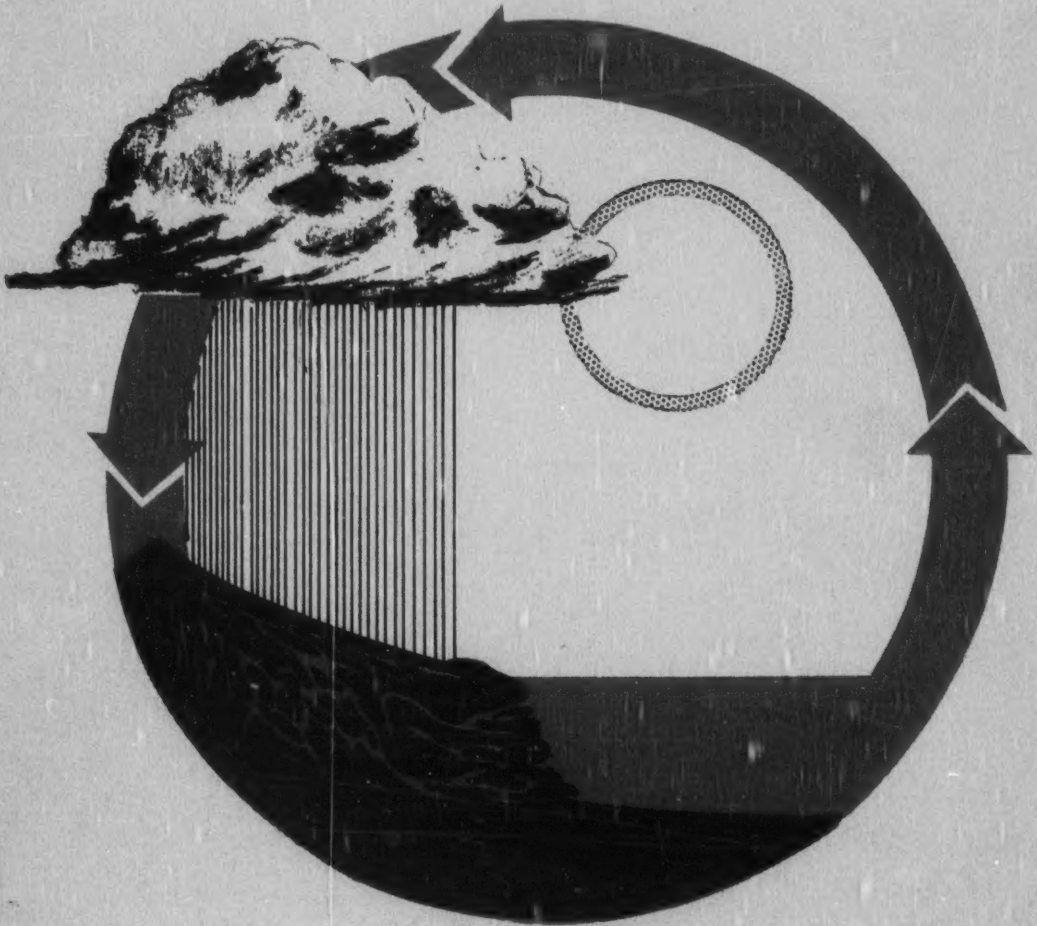

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PESTICIDES IN THE
AQUATIC ENVIRONMENT

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Environmental Protection Agency
April, 1972

ENVIRONMENTAL PROTECTION AGENCY
WASHINGTON, D.C. 20460

SEP 1 1 1972

OFFICE OF THE
ADMINISTRATOR

The President
The White House
Washington, D. C. 20500

Dear Mr. President:

We are pleased to submit to you a report entitled "Pesticides in the Aquatic Environment". It was prepared in compliance with Section 5 (ℓ)(2) of P.L. 91-224. Federal agencies concerned with pesticides problems contributed to the report.

P.L. 91-224 mandates your submission of the report to the Congress along with your recommendations for any necessary legislation. A draft of a letter of transmittal to the Congress, including a legislative recommendation, is attached for your consideration.

We believe this document will be of substantial value to those engaged in program planning and development, legislative activities and research. It should also be of value in developing action programs involving pesticides in a general management of the environment.

Respectfully,

William D. Ruckelshaus

William D. Ruckelshaus
Administrator

Enclosure

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FOREWORD

The Water Quality Improvement Act of 1970 (PL 91-224) became effective on April 3, 1970.

Sections 5(ℓ) (2) of the Act requires that "For the purpose of assuring effective implementation of standards adopted pursuant to paragraph (1) the President shall, in consultation with appropriate local, State, and Federal agencies, public and private organizations, and interested individuals, conduct a study and investigation of methods to control the release of pesticides into the environment which study shall include examination of the persistency of pesticides in the water environment and alternatives thereto. The President shall submit a report on such investigation to Congress together with his recommendations for any necessary legislation within two years after the effective date of this subsection."

This report has been prepared by the Office of Water Programs, EPA, in fulfillment of the requirements of this Section of the Act. Members of the Technical Advisory Committee and consultants who aided in preparation of the report are shown at the end of the report. The pesticide study contracts utilized in the report preparation are also listed.

SUMMARY

Early use of pesticides for health and crop protection emphasized the value of pesticides to the Nation. Millions of lives have been saved through vector control programs. Catastrophic crop damage from insects and weeds has been minimized through the use of modern pesticides. Many areas now are favored recreational sites because pesticides have controlled vicious biting insects. Carpets and clothing are provided a high degree of protection from damaging beetles and moths and, generally, pesticides have provided a higher quality of life for man.

A general awareness exists that under many circumstances the use of pesticides also carries a negative value, because they frequently cause slight to severe environmental damage. Monitoring data have shown that pesticides are ubiquitous in the water environment. It is now well established that pesticides can move into areas many thousands of miles removed from the site of application as illustrated by measurable levels of DDT in antarctic penguins which have never been directly exposed to this pesticide. As with many other manmade pollutants, it has been found that pesticides can overpower nature's capacity to dilute and detoxify noxious chemicals.

Pesticide Entrance Into the Aquatic Environment

The physical and chemical properties of pesticides govern their movement from one ecological system to another. These properties are only well understood for a few pesticides. However, it is known that the processes which regulate the rate of movement of pesticides from soil into water are influenced by the clay and organic content of the soil, the degree of cation saturation within the soil, solubility of the pesticide, temperature, and climatic conditions. Degradation of the chemicals by sunlight and oxygen and by acid and microbial enzyme action, leaching, and uptake by plants cause removal of the pesticides from the soil and thus influence their transport to the aquatic environment.

The route of pesticides to the aquatic environment may be either direct or indirect. Routes such as application of a pesticide to water for the purpose of pest control or the discharge of pesticides as industrial wastes are considered to be direct. Pesticides may enter the aquatic environment indirectly with land drainage or erosion from pesticide-treated areas or by volatilization and subsequent fallout or washout from the atmosphere.

Pesticides may enter surface waters as a result of drift from aerial applications, overland drainage, intentional dumping, discharge of wastewater from the cleaning of contaminated materials and equipment, incinerator and open burning gaseous and particulate discharges, wind-blown treated materials, and accidental spills. Agricultural, commercial, and domestic applications can all result in significant discharges of pesticides to the aquatic environment.

Soils are an important terrestrial sink for pesticides. They control the movement of the chemical through the processes of adsorption, degradation, leaching, and/or vaporization. Movement of pesticides from land may take several forms but land drainage is the most significant. The occurrence of pesticides in waterways and their subsequent mobility in the aquatic environment are primarily due to their adsorption on small particles in runoff waters.

Impact of Pesticides on the Aquatic Environment

Once in the aquatic environment, pesticides may enter aquatic organisms either directly through ingestion or absorption of contaminated water or indirectly by feeding on previously contaminated organisms. Filamentous algae may accumulate large amounts of chlorinated hydrocarbons which are then passed on to animals higher in the food chain.

On a cellular level, pesticides can inhibit cell division, photosynthesis, and growth; alter membrane permeability; change metabolic pathways; and inhibit the action of enzymes, including those functional in metabolizing steroid hormones (i.e., estrogen and testosterone), and the enzyme which is functional in the deposition of calcium carbonate in eggshells. Blood changes, systemic lesions in the brain, spinal cord, liver, kidneys, and stomach, and subsequent susceptibility to bacterial and fungal infections may ensue.

Storage of pesticide residues in the bodies of aquatic organisms may affect the vitality of developing larvae and may lead to premature termination of gestation and a reduction in the number of young. Breeding cycles and migratory patterns may also be interrupted.

Acute pesticide poisoning may result in immediate fish kills. Chronic effects, which ensue if the degree of exposure of an animal to a pesticide exceeds the capacity of the animal to detoxify and eliminate the pesticide residues, may cause structural imbalance in an entire aquatic community. Reduction in food supply, with subsequent reduction in predator populations, and acquired resistence or increased sensitivity to certain pesticides may lead to elimination of top-level carnivores.

The threshold of toxicity may be a critical factor. Some estuarine organisms such as oysters reach an equilibrium level with the concentration of the pesticides in the surrounding water. Other organisms that can exist in estuaries with low levels of DDT, for example, may be seriously affected by a sudden moderate increase in the pesticide residues, such as might enter the water through runoff.

The occurrence of low level concentrations of pesticides in drinking water must be evaluated relative to human health. Chlorinated hydrocarbon residues at microgram per liter concentrations are not completely removed by most water treatment practices. Chlorine treatment has oxidized the organophosphate parathion to the more toxic derivative paraoxon. Percolation through a granular bed seems to be the most effective method of water treatment.

Pesticide toxicity must be evaluated in a total environmental context, since physical factors such as pH, temperature, salinity, the presence of other chemical compounds may affect the toxicity of a given pesticide. The surface-to-volume ratio of the organism, and the developmental stage of the animal may alter the toxicity of any given pesticide.

Persistence of Pesticides in the Aquatic Environment

The fate of pesticides after application may involve biological and photochemical degradation, chemical oxidation and hydrolysis, direct volatilization and migration into adjacent areas, translocation into plants, and sorption onto airborne particulates and soil materials. The pathway for degradation of a given pesticide depends upon temperature, oxygen concentration, and the presence of other reactive substances.

Aquatic vegetation can take up large quantities of pesticides. These substances can be degraded inside the plant or stored. The stored compounds may either become part of a food web or be returned to the water or sediment. Fish and filter feeding sedentary invertebrates take up pesticides directly from the water. Residue levels within them are associated with water concentrations, and are directly related to seasonal agricultural practices and rainfall.

The sorption of pesticides by suspended material and substrates in natural waters is an important factor in the degradation process. It may facilitate hydrolytic reactions and translocation of pesticides to areas favorable to microbial degradation.

Pesticide concentrations in the ug/kg range may be found in the sediments of small ponds and estuaries even though no detectable concentrations are found in the overlying water. However, the pesticides in the bottom sediments may be recycled to the overlying water. This recycling can result from fall and spring overturns following temperature change or from the release of pesticides from the sediments.

The chemical degradation products of certain chlorinated hydrocarbons and carbamates are many times more toxic than the parent compounds. This is true for photoisomers of aldrin/dieldrin and heptachlor and for the sea-water hydrolysis product of carbaryl. The difference of a day or two in the application of malathion to adjacent fields can result in the presence of both malathion and its breakdown product diethylfumarate, with which it is synergistic, in runoff waters.

The most widely occurring pesticides in water are chlorinated hydrocarbons, which can persist for many years. In general, organophosphates, carbamates, and herbicidal compounds disappear from the water within a matter of a few weeks or months.

Polychlorinated biphenyls used largely in manufacturing have been used with pesticides as vapor point depressants in the past. The presence of these compounds in water, biota and sediments is widespread. These compounds are stable, and they bioconcentrate in tissues and interfere with calcium deposition in egg shells. A similar effect has been demonstrated with DDT.

Pest-Control Alternatives

A method of pest control can be effective if it has a direct adverse effect on the pest species or if it modifies the conditions necessary for the survival of the pest. Simple cultural methods involving crop rotation, destruction of crop refuse, cleaning of field borders, alteration of time of planting, and fallowing can be very effective against certain pests. Use of fire, of UV or blacklight lamps, and of resistant varieties of crops are other effective pest control methods.

The use of parasites, predators, and pathogens as biological control agents is promising because these agents are quite specific in their targets and are harmless to other animals and plants.

Release of sterile animals into a normal population can effectively curtail he ability of a pest population to reproduce. Chemical sterilants such as apholate and aphoxide can have the same effect.

The development of sex, food, and oviposition attractants and repellants is now in progress. Synthetic insect hormones that regulate growth, feeding, mating, reproduction, diapause, and overwintering are currently under study. Ecdysone, which initiates the shedding of skin or the onset of metamorphosis may prove to be particularly effective. Hormones have an additional asset in that it is impossible for insects to develop an immunity to them.

Seed laws and seed certification may significantly reduce the need for herbicides, while quarantine, regulatory controls, and pest surveillance may further reduce insecticide use.

Integrated control, the approach favored by this Administration,[1] makes use of all available methods of pest control in a complementary fashion. The development of safer and more selective chemical pesticides could be a significant part of the integrated control program.

CONCLUSIONS

Analysis of the information gathered during this study both pinpointed beneficial work which has been done and highlighted areas where sufficient information does not exist for definite conclusions on the extent of pesticide problems.

1. Although the use of pesticides during the past several decades has contributed materially to the economic well-being of the country and has been beneficial to the health of the population by controlling insect disease vectors and pests, damage to many aspects of the environment may have had an indirect and insidious influence on the health and welfare of the population.

National objectives for the investigation of the influence of pesticides should be promulgated. A primary national objective should be the protection and enhancement of the environment. Decisions with regard to pesticides should reflect an assessment of the real need for the pesticide, including:

a. an evaluation of the degree of economic damage by a given pest or type of pests tolerable to a specific area of agriculture, thence to the economy;

b. a determination of the need for one or more pesticides to control the pest or pests; and

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[1] See Integrated Pest Control Program described in the President's 1972 Environmental Message to the Congress.

c. an assessment of the actual value of a given pesticide through cost-benefit analysis. This assessment should include costs of damages to fish, wildlife, and beneficial insects as well as the benefits from pesticide use.

2. It is estimated that between 700 and 800 million pounds of pesticide active ingredients are being used in the United States each year. It is further estimated that farm uses of pesticides account for approximately 50 percent of the total domestic use. No comprehensive quantitative information is available on the urban-suburban, industrial, and Federal, State and local governmental uses of pesticides. The lack of comprehensive information on the use of pesticides impedes an objective analysis of their effects on the environment. An effort is needed to centralize and analyze information on pesticide use in order to enhance the development of programs for their control.

3. Pesticides are found universally in surface waters of the United States. In some instances, a reduction in the population of both aquatic and terrestrial animals has resulted from the tissue accumulation of pesticide residues, the levels of which are generally proportional to the persistence of the chemical. The reduction in the total use of persistent pesticides starting in 1967, has reduced residue levels in some areas of the United States.

4. Pesticide application efficiency is generally low and large losses to drift and vaporization occur. Methods and equipment for increased efficiency of application of pesticides are being developed and should be used. Better methods and equipment materially reduce the necessary levels of application.

5. A comprehensive evaluation of potential alternatives must be made and combinations of these used in an integrated management program. The wide variety of specific alternatives to pesticides for pest control should be intensively investigated. Where feasible these alternatives should be implemented in integrated pest control programs.

6. Improved assessment programs, including use of improved sampling and analytical techniques, are necessary to acquire information on pesticide release; routes through, effects on, and the ultimate fate in aquatic systems; and the capacity of the aquatic environment to degrade the pesticides.

7. Greater emphasis should be placed on field investigations to determine:

a. persistent pesticide sorption and desorption in relation to specific soils and aquatic bottom sediments;

b. dynamic forces contributing to movement of pesticides in aquatic environments;

c. specific pesticide degradation mechanisms and rates, and products and toxicities, in the various fresh, brackish and salt water bodies;

d. the extent and prolonged effects of pesticide spills. At present, notification is voluntary. The Environmental Protection Agency was notified and responded to 11 such accidents in 1971.

8. Research and development should be organized and modified through existing agencies to provide more complete information on the effects of pesticides on the environment and develop methods for their control. All aspects of pesticide manufacture, formulation, distribution, use and disposal should be evaluated in terms of their environmental impact. Pesticide training and technical assistance programs should also be strengthened.

a. Additional methods to determine the toxicity of pesticides and metabolites to indicator species of aquatic organisms should be developed and these methods should be used to monitor the environment.

b. Chemical, physical, and biological methods, or a combination of these, to degrade (detoxify) unwanted chemicals should be developed. The investigations of various alternatives should include but not be limited to: soil dissipation; thermal, chemical and biological degradation; recycling; and bulk distribution to eliminate the use of disposable containers.

c. The development of biological methods for extraction (uptake and concentration) of chemicals out of soil and water should be assessed. While uptake by algae is known, the impact of pesticides on these biological cleaners should be elucidated.

d. More information needs dissemination. Public agencies, gardening organizations, and home and garden pesticide manufacturers should be encouraged to cooperate in furnishing advice on how to control pests around the house and yard in such a way as to reduce actual and potential harm to the environment to a minimum.

9. The investigation, elucidation and control of the transport of pesticides into the aquatic environment and their toxicological influence, both acute and chronic, will be greatly dependent upon the nature and scope of monitoring systems.

A program of chemical and biological monitoring should be implemented on major drainage basins in areas of heavy pesticide application. Reference and control areas should be studied as well. Correlations between kinds and amounts of pesticide application, hydrologic cycle, and a pesticide inventory in soil, sediments, water and in the biological food web at the producer, primary consumer and top carnivor trophic levels should be established at various points in the basin on a routine basis. Such a program should be implemented to evaluate the effects of pesticides on the structural and functional characteristics of aquatic communities (i.e., respiration, photosynthesis, waste assimilation, energy flow, diversity, etc). The periodicity of potential susceptibility of aquatic life to pesticides should be integrated into policies on kinds, amounts and types of application techniques used. Some aquatic communities are more vulnerable to pesticides at times of spawning or at other critical times in their life cycle. Other environmental considerations such as temperature, hydrologic conditions, amounts of organic material present, etc., should be considered prior to use of a pesticide that has the potential to enter an aquatic system.

Monitoring programs should be designed to assess rates of accumulation in various portions of the food chain as well as the existing body burden. It is not necessary to establish this type of monitoring on all drainage basins but only on a small portion of the major types. Particular attention should be addressed to those organisms under heavy predator pressure. Those organisms which are less acceptable as food, such as blue-green algae, need less attention.

INTRODUCTION

Quantities of Pesticides Used

The United States has traditionally grown crops, such as cotton, tobacco, vegetables, citrus, peaches and corn, which require application of large quantities of pesticides for profitable production. In the past, the Southeast has accounted for the largest share of organochlorines used in the United States (1). Control of pests in cotton alone has consumed 70 percent of the total DDT used nationally (2). The use of pesticides has been an almost inevitable consequence of the development of modern intensive agriculture. High production characteristics of new hybrid varieties, monoculturing of crops and minimum tillage practices have increased the need for pesticides (3).

Table 1. Pesticide Usage in the U. S. A. (3)

Year	Sales in million of pounds			
	Fungicides	Herbicides	Insecticides	Total
1962	97	95	442	634
1963	93	123	435	651
1964	95	152	445	692
1965	106	184	473	762
1966	118	221	502	841
1967	120	288	489	897
1968	124	318	498	940
1969	127	348	502	983

Information on principal usage, types and volumes of pesticides is important in this era of national concern for the environment. It is particularly vital in the determination of the extent and trends of environmental pollution from persistent pesticides.

Concern for the total quantities of pesticides applied for control of agricultural pests, and the associated chronic health hazard to the public and the environment, is of recent origin. Consequently, laws do not generally exist which require pesticide manufacturers, distributors, or users (growers) to report actual quantities of pesticides sold or applied in the different states to any state or Federal agency. The absence of such reporting prohibits an accurate inventory of pesticide usage by states or regions.

History of Pesticide Use

Plant protection by the use of chemical sprays or dusts or seed treatment did not originate in the 20th century but has been practiced on a small scale since ancient times. However, large scale farming practices of the twentieth century have hastened the evolution of pesticide compounds and their use.

The first insecticidal materials included the arsenicals, lime-sulphur, petroleum oils and nicotine. Between World Wars I and II, flourine compounds, pyrenthrum, rotenone, synthetic organic materials, (e.g., dinitro compounds) and thiocyanates came into use. Discovery of the pronounced insecticidal activity of DDT in 1942 led to concerted efforts by chemists and entomologists to find other potentially effective insecticides. These efforts led to discovery of such compounds as benzene hexachloride, toxaphene, chlordane, aldrin, dieldrin and several organic phosphates.

The history of weed control in crops began with the use of salt, ashes, and smelter wastes. From 1887-1900, copper salt was used to selectively kill broad leaf weeds in cereals. Copper sulfate has been used extensively for algal control since 1904. When used excessively it can poison fish and other aquatic life, and it may accumulate in bottom muds as an insoluble compound (4). In 1900, calcium cyanide was added to the list of selective herbicides. Ferrous sulfate, copper salt and sodium arsenite were used before World War II. The auxin activity and selectivity of 2,4-D were discovered in 1942 and 1944, followed by 2,4,5-T in 1948 and phthalmic acid in 1952. Many other herbicides belonging to the groups such as substituted ureas, carbamates, triazines and substituted phenols have been developed and are presently being used (5).

The history of fungicides use can be divided into three distinct eras. These are the sulfur Era (from ancient times to 1882), the Copper Era (1882 to 1934), and the Organic Fungicide Era (began in 1934). During the 19th century however, two classes of inorganic fungicides, first sulfur, either alone or as lime sulfur and then copper, principally a mixture of copper sulfate and lime called Bordeaux mixture, was applied to foliage to protect plants from disease fungi. These developments continued and by the 1930's many of the important foliar diseases were controlled by spraying or dusting with some form of either copper or sulfur. In spite of the subsequent development of organic fungicides, sulfur and copper fungicides are still being used. However, the quantities of each being applied are decreasing (6).

Concurrent with the early development of foliage fungicides, development of chemicals for the control of seed-borne bunt or smut fungi of cereals occurred. The use of copper sulfate soaks was popular for a time followed by the introduction of formaldehyde and copper carbonate. In the early part of this century organic mercury compounds for seed treatment were developed, the first was a chlorophenol mercury. The use of nonmercury organic fungicides began in 1934 with the issuance of a patent covering a variety of derivatives of dithiocarbamic acid. Their development was slow but in the early 1940's thiram was introduced for seed treatment.

THE ROUTE OF PESTICIDES INTO THE AQUATIC ENVIRONMENT

After two decades of intensive use, pesticides are found throughout the world. They are present, even in places far from any sprayed site, in both the aquatic environment and the atmosphere. While sufficient information is not presently available for a full assessment of the effects on the aquatic environment from various sources, a general appraisal of the routes of entry can be made.

Direct Application

Many organic pesticides are added directly to water to control aquatic insects, trash fish, and aquatic plants. Most of these applications are made for a particular purpose and the amount of pesticide added is closely controlled. However, control of the amounts may be lax in massive applications such as emergency mosquito control. In some cases, non-target species may be affected as well as the insects, fish or plants to be controlled by the pesticide application.

Toxaphene and rotenone have been used to control various species of fish (8). Also it has been found that fintsol can be used more effectively than rotenone for controlling sunfish in catfish ponds (9). Aquatic weeds have been controlled by the application of herbicides (Karmex, copper sulfate, Kuron, and 2,4-D) (9). High rates of 2,4-D application for water milfoil control in Tennessee Valley Authority reservoirs have not produced acute effects on aquatic fauna or water quality (10).

Dieldrin was applied at a rate of 1 lb/acre in 1955 to 2000 acres of salt marsh in St. Lucie County, Florida during a sand fly eradication program. An estimated 1,117,000 fish representing some 30 species, were killed following which reproduction was not observed for four weeks (11, 12).

Agricultural and Urban Land Drainage

Not all the pesticides applied to land end up in a waterway, but it is likely that the majority of the pesticides in streams result from storm runoff or overland flow (13, 14, 15, 16, 17). Pesticides are used for the control of pests in agricultural areas and in parks, golf courses, home lawns, and gardens in the urban areas.

Agriculture is the chief consumer of pesticides, using approximately 51 percent. Although comprehensive statistics on urban use are not available, it is reasonable to assume that this use accounts for a large percentage of the remaining pesticides.

Soluble pesticides may enter surface waters dissolved in the water draining the lands. However, it is believed that most of the pesticides reach the water with the sediments washed from the land. Pesticides are sorbed initially onto particulate matter and then transported as complexes to the water course (13). Chlorinated hydrocarbons are found extensively in surface waters of the United States (18, 19). Since chlorinated hydrocarbons are only slightly soluble in water, they may be transported as a film, emulsion, or in association with particulate matter. Chlorinated hydrocarbons have been found in bottom sediments at 126 locations in the Mississippi River where the deposits are attributed to agricultural sources (20, 21).

Soil Erosion

Gross sediment eroded in the United States is estimated to be around four billion tons each year. This loss occurs by the processes of sheet erosion, gullying, and stream channel erosion (22). Eroded soils previously treated or incorporated with pesticides are major sources of surface water contamination (23).

An investigation of atrazine associated with runoff and erosion was made using simulated rainfall and surface applications to soil. It was found that greater losses resulted when the rain was applied immediately after the herbicide application. The atrazine content was highest in the soil fraction of the washoff and the water-soil mixture content was higher than the water fraction (24). Simulated rainfall intensities and storm duration were used to investigate 2,4-D contained in washoff from cultivated fallow Cecil sandy loam soil (25). Concentration of 2,4-D in the washoff were positively correlated with the application rate and were greatest at the beginning of each storm. The isooctyl and butyl ether ester formulations of 2,4-D were far more susceptible to removal in washoff than the amine salt (25). For dieldrin-incorporated soils, losses were appreciable when erosion occurred and reached 2.2 percent of the amount applied (26).

Effects of soil cultivation on the persistence and vertical distribution of pesticides were investigated over a ten-year period (27). After treatment DDT and aldrin were rototilled into the soil. First one-half of each plot was disked to a depth of approximately 5 inches for 5 consecutive days each week for a 3-month period. The other half served as a nondisked control. While only 26 percent of the applied DDT was lost in a 4-month period from the nondisked portion, 44 percent was lost from the disked portion. For aldrin, 53 percent was lost in the nondisked and 70 percent in the disked plot. No difference in the distribution of the residue in the soil layers was found between disked and nondisked soils.

Runoff of Soluble Pesticides

All pesticides are soluble in water with the degree of solubility varying from very slight to great. In general, organic phosphates are more soluble than chlorinated hydrocarbons. Various herbicides, particular the inorganic compounds, are highly soluble in water.

The greatest danger from runoff of soluble pesticides is in the period immediately following their application and prior to the time required for them to become sorbed into the soil. To some degree, this condition is controlled in major agricultural areas since weather conditions are closely observed and to some extent control the time of pesticide application. The same cannot be said for the home lawn or weekend garden applications.

Water solubility, although important in the physical transport of the pesticide from the area of application, is not considered to be the major factor in leachability. A very water-soluble compound will not leach if it is irreversibly sorbed and an insoluble compound will leach readily if it is not sorbed (28). The moisture content of the soil, as well as the intensity and frequency of rainfall, affects the overall movement of pesticides in the soil. A low moisture content favors retention of the pesticide in soil because it lowers total solubility and enhances the competition of the pesticide for an absorption site. Bailey reported that the frequency, length, and intensity of rainfall must be considered together in projecting herbicide losses from the upper soil horizons (12). Certain pesticides are leached in greater amounts and to greater depths under lower rainfall intensities. Weather patterns may be as important as total rainfall in determining the movement of herbicides in soil (29).

Atmospheric Processes

Pesticidal compounds may enter the atmosphere in several ways and in various physical states and then be redeposited directly or indirectly into the aquatic environment. Direct drift from spraying operations contributes particulate or globular matter at concentrations that are likely to vary inversely with the distance from the site of application. Such effects are usually local but the possibility exists for a more extensive influence. Several organochlorine insecticides volatilize from treated soils, thus adding a slow but long-term contribution to the atmosphere (30). Effluents and vapors from industrial processes, such as pesticide manufacturing or moth-proofing of garments, also contribute. Quantities may accrue from the use of domestic aerosol insecticides and thermal vaporizers and the dust from treated soil, clothing, and carpets. The concentration of these compounds in air is lower by a factor of 10 to 100 times that of rainwater (30).

Pesticides can be transported by wind and deposited in water far from an area of application. Even a trace of precipitation may deposit unusually large amounts of pesticides on sites far from the source of the contamination if it falls through windblown dust clouds. Pesticides are now considered to be universally present in the air. Their distribution to sites removed from application areas depends on prevailing patterns of wind circulation and deposition rates. The potential for atmospheric contamination and subsequent transport during field application of pesticides is great.

Volatilization

Pesticide residues may enter the atmosphere by codistillation from water surfaces (31, 32, 33), by vaporization from plants and soils (34), and by aerial drift during application. The DDT residues in precipitation may average as much as 1,000 parts per trillion (35). Based on only a precipitation content of 80 parts per trillion, some have estimated the total annual losses to be as much as 2 pounds per acre per year in the summer and about 0.3 pound per acre per year in the winter (36).

A direct relationship between the initial DDT concentration (below 100 ug/l) and the DDT codistillation rate has been reported (33). At the highest concentration tested (1,000 ug/l), the codistillation rate was as much as six times greater than anticipated by theoretical dissemination equations. This finding is in agreement with DDT's great affinity for the air water interfaces, which facilitates the high codistillation rate.

Vapors are given off from aldrin-, heptachlorphorate, lindance, heptachlor epoxide, and dieldrin treated soils (37). An increase in the rate of aldrin volatilization from the soil resulted from increases in insecticide concentration in the soil, soil moisture, relative humidity of air passing over the soil, soil temperature, and the rate of air movement over the surface of the soil. A decrease in the rate of aldrin volatilization was noted in dry soils containing increasing amounts of clay and organic matter and in wet soils containing increasing amounts of organic matter. Vapor loss of trivluralin from water was found to be proportional to concentration (38). Placement of the herbicide below the soil surface (0.5-inch) resulted in a very low vapor loss for both moisture regimes.

Dusting and Spraying

Fallout from aerial pesticide application is a principal source of water contamination (17, 35, 39, 40). High levels of the atmospheric contamination by pesticides (DDT, toxaphene, parathion, and organophosphate) have been measured in agricultural areas such as Dothan, Alabama; Orlando, Florida; and Stoneville, Mississippi. Higher pesticide levels were found when pesticide spraying was reported than when no spraying was in progress (41).

Aerial pesticidal sprays usually reach the target in amounts equal to or less than 50 percent of the quantity distributed(40). During practically every spray operation, many nontarget organisms are killed. DDT residues may travel great distances once in the atmosphere, and eventually enter the aquatic environment through precipitation or dry fallout processes. Pesticidal drift from Mississippi cotton field applications has killed a large number of fish, snakes, frogs, turtles, and some egrets (40). Aerial spraying of organophosphate pesticides on farm land has caused severe poisoning of a farm worker and the death of a 16 year old boy (41).

Windblown Material

Wind can sweep away surface soil to which pesticides are sorbed. These particles can be deposited into the aquatic environment by rain or by settling processes (17). High winds have created dust clouds from which precipitation has deposited an unusually large amount of contaminated soil. In this case, selected samples showed 1.3 parts per million of total chlorinated hydrocarbon. Pesticides detected were chlordane, heptachlor epoxide, DDE, DDT, ronnel, dieldrin, and 2,4,5-T (43). Deposits of malathion and azinphosmethyl following aerial application were measured at various wind speeds and flight altitudes. These pesticides were detected as far as 800 meters (1/2 mile) downwind from application. Estimated recoveries from the adjacent areas, into which the spray drifted, ranged from 18 to 96 percent of the amount applied (44).

Analysis of rainwater and dust have revealed the presence of chloro-organic substances in samples examined. Proof that pesticides can be transported to earth by rainfall was obtained from a deposit of dust on the Cincinnati, Ohio area on January 26, 1965 (45). It is reasonably certain that soil is constantly being picked up by winds, transported at high altitudes over long distances, and deposited elsewhere either by sedimentation or by rain.

Waste Disposal

The entry of pesticides into the aquatic environment because of waste disposal results from two main causes. First, the liquid wastes containing pesticides may be discharged from industrial plants or indirectly with sewage treatment plant effluents. Second, the disposal of excess pesticides or used containers may result in a direct entry of pesticides into the aquatic environment.

Industrial Waste Disposal

The wastes from pesticide manufacturing and formulating plants, unless very closely controlled, contain pesticides. In addition, the effluents from plants that use pesticides in their processes may contain variable amounts of pesticides. At present, comprehensive information for evaluating the extent of these sources of pesticides is not available. However, the following summaries from case studies are cited to illustrate this type of pesticide entry into the aquatic environment.

A parathion and methyl parathion manufacturing plant in Alabama dumped its effluent into a creek when its treatment plant failed in 1961. Fish, turtles, and snakes died along 28 miles of the creek and traces of parathion residue were recovered from the Coosa River into which the creek emptied (16.)

Five pesticide-formulating companies in the lower Mississippi River basin dumped waste materials into city sewers; channels and sloughs near their plants, and onto city and private dumps in the vicinity of waterways. Pesticide residues, varying from less than 0.5 ppm in river mud to thousands of ppm in the vicinity of the plants, were found in the basin (2).

Dieldrin, used in an Augusta, Georgia wool scouring plant, was discharged into the Savannah River. Prior to the use of an alternative, a similar plant used and discharged dieldrin into the Ogeechee River (46).

Disposal of Excess Material and Containers

The problem of the ultimate disposition of pesticides can be separated into two categories, namely; the disposal of pesticide residues and waste; and the disposal of pesticide containers. Mississippi State Universtity has conducted overview studies of the pesticide disposal problem (47, 48). The waste disposal problem was classified into three general categories, namely; disposal by land burial; disposal by chemical and thermal methods; and recycling of waste and containers.

Mixtures or formulations are more biodegradable than single pesticides, provided that at least one or two of the pesticides in a mixture were relatively easy to biodegrade (47). However, biodegradation in soil may result in the suppression of soil bacteria and favor growth of Streptomyoetes and other fungi. If the bacterial population is suppressed for an extended period of time, important processes such as nitrification, nitrogen fixation, sulfur tran formation, and others are endangered. Thus, the burial of pesticides presents problems beyond the contamination of water.

Chemical and thermal disposal methods were compared and it was shown that incineration was superior to chemical methods (48). Incineration at 800 to 1,200 degrees centigrade for five minutes is the most effective method of pesticide wastes. However, the process in itself is not entirely satisfactory. Incineration without the entrapment of pesticides in the resulting gases represents an environmental threat through air pollution. Volatile pesticides and their degradation products could conceivably endanger the surrounding countryside. Another serious problem arises from the residue that remains after incineration. The quantity of residues can be considerable and the residues may retain other toxic elements, such as arsenic. If disposal of pesticide residues is by burning, it is possible that further chemical treatment will be needed.

Little is known about pesticides released from incineration of municipal and industrial wastes and treatment plant sludges. Because of the large quantities involved, atmospheric releases could be significant and widely dispersed.

Disposal of pesticide containers presents a particular problem. These containers retain substantial residue. If the container, such as a metal drum, is recycled, this problem is lessened. However, if these containers should be disposed by dumping, the buildup of toxic material could be significant and the material could subsequently be transported to other areas by water movement.

The magnitude of the problem can be illustrated by an example. The number of containers reportedly used in the state of Mississippi in 1969 were (49):

55 gallon drums	65,750
30 gallon drums	16,000
5 gallon drums	240,000
1 gallon drums	401,000
0.5 gallon (glass, metal & plastic containers)	35,000
0.25 gallon (glass, metal & plastic containers)	80,000

A 1970 survey of 75 counties in Tennessee indicated that 3,332 empty pesticide containers were discarded as trash (49).

Much remains to be accomplished with respect to the safe disposition of used containers with pesticide residues although industry is developing guidelines (50). A nationwide disposal system should be initiated as soon as possible. Open burning should be prohibited, even in rural areas, because of air contamination.

The following three case studies illustrate this type of pesticide entry into the aquatic environment.

A fish kill took place in Indian Swamp, North Carolina, on or about June 10, 1971. This occurred when a person deliberately discharged about two gallons of chlordane solution into the surface waters. On June 14 and 15, 1971, Indian Swamp waters exceeded from 2 to 10 times the recognized toxic limits of chlordane (51).

Over-aged parathion bags (15 percent dust) were dumped into the Peace River near a bridge one mile upstream from the municipal water intake of Arcadia, Alabama, a town of 6,000 people (16). All but 8 to 12 bags were eventually recovered. Subsequent analysis showed less than 1 mg/l concentrations in the local water distribution system.

Drums containing chemical wastes have been found in and along the North Sea. The wastes were analyzed and found to contain lower chlorinated aliphatic compounds, vinyl esters, chlorinated aromatic amines and nitrocompounds, and the insecticide endosulfan (53). This could occur in the United States where pesticidal wastes and containers require disposition.

Accidental Spills

Unintended entry of pesticide in water systems can result from accidents, spills, poor disposal practices, and catastrophies. The possibilities are unlimited and much needs to be done to bring this route of entry of pesticides into the aquatic environment under control.

The following selected case studies are presented as examples of accidental entry of pesticides into waterways.

On September 4, 1967, a truck lost a drum of malathion in Cordele, Georgia (46). The malathion spilled in the street. The local fire department was called to clean up the street as a traffic safety precaution. The malathion was washed into the storm sewer system which discharges into Gum Creek, a tributary to the Flint River impoundment, known as Lake Blackshear. A 0.32 inch rainfall occurred that night. The next day a massive fish kill was reported in Gum Creek. On November 2, 1969 another fish kill was reported on Gum Creek (54). By November 4, fish were dying over a three mile reach of the stream downstream from the Cordele wastewater treatment plant. Approximately 1,500 fish were killed.

In March, 1965, 2,500 to 3,000 pounds of 5 percent chlordane wettable powder were spilled from a truck passing through Orlando, Florida. Although as much as possible was salvaged from the street, about 1,300 to 1,700 pounds were lost into the street's storm drainage system from which it passed into a dry creek bed near one of the city's lakes. When the potential danger to the lake was realized, the concentrated water and soil were collected and disposed (16). The study did not cite the means of disposal.

A comprehensive examination has been made of a shallow farm well contaminated with persistent pesticides (55). The well was located less than 25 feet from a site previously used for flushing an insecticide sprayer. Pesticide levels in the water have been monitored for more than 4 years, during which time a gradual decline in concentration has occurred. Soil core samples indicate a relatively high surface contamination but very little downward percolation. Sediment samples from the bottom of the well exhibit the highest concentration of all samples.

On June 20, 1971, a fire of about ten hours duration occurred at an agricultural chemical warehouse in Farmville, North Carolina (56). The warehouse contained a wide assortment of hazardous chemicals including pesticides. Water was used to extinguish the fire. Dikes were constructed to retain these waters until they could be pumped to polyethylene-lined pits. This particular incident indicates the need for a rapid response program for unusually hazardous situations.

Disastrous effects on aquatic life have resulted from the fire ant control program of the Southeast United States. In Wilcox County, Alabama, most adult fish were killed within a few days after treatment. Fish from ponds in a treated area of Florida were found to contain residues of heptachlor and a derived chemical, heptachlor epoxide (57).

Mirex has been used extensively since 1962 in the Southeast to combat the fire ant. Mirex was to be applied aerially over 125 million acres. The project was to require twelve years and cost an estimated $ 200 million (46). Mirex is highly persistent in the natural environment and has been shown to be moderately carcinogenic when injected in laboratory mice (58, 59). However, subsequent long-term studies have demonstrated chronic toxic effects on crabs and shrimp. Eighty percent mortality in shrimp and 60 percent mortality in crabs occurred when they were exposed to only 0.1 mg/l mirex in water for 15 days (60). Because it is very insoluble in water and very soluble in animal fat, the chemical moves rapidly from water into aquatic species and through the aquatic food chain. Current spraying techniques involve a bait made up of ground corncobs impregnated with soy oil and mirex. This is a risky practice because the untouched bait may eventually be carried into waterways by runoff. Incorporation of the bait into the soil may solve this problem. A national survey of 5,000 oysters and other shellfish has demonstrated that mirex is the fourth most commonly found pesticide residue (60). It was also reported that mirex contaminates shellfish in estuarine drainage areas of the southern states.

Although awareness of safety in handling pesticides is increasing, the task gets more complex as new chemicals are developed. Educational efforts must reach the entire population including scientists, regulatory officials, educators, industrialists, and the users of pesticides. The reasons for accidents are preoccupation, clumsiness, forgetfulness, disregard, inattentiveness, unpreparedness, distraction, and in general, a common denominator - lack of awareness (61). The goal must be complete protection of the food supply from pesticide residues, protection of the aquatic environment from pesticide contamination and total elimination of pesticide accidents (62). Safe handling procedures in pesticidal application must be followed by all users to prevent future accidental spills (50, 62, 63).

THE EFFECTS OF PESTICIDES ON THE WATER ENVIRONMENT

Introduction

Benefits derived from pesticides are measured by their effectiveness in reducing populations of pest species and conversely, detriment is equated with adverse effects on nontarget species (64). Because pesticides are rarely applied only to the target species, nontarget species mortality continues.

Movement of Pesticides by Aquatic Organisms

An aquatic organism may be exposed to pesticides through several mechanisms: direct entry of pesticides into the habitat, movement of an organism into areas previously contaminated by and retaining pesticides, transportation of pesticides from contaminated habitats via suspended material or other "carriers," or a combination of these. Uptake of pesticides by aquatic organisms may be direct or indirect. Direct uptake refers to ingestion or absorption either from direct contact with the pesticide or from various abiotic, pesticide contaminated attributes of the aquatic environment (1). Indirect or secondary exposure results from oral ingestion of organisms previously contaminated by pesticides. For example, such exposure occurs as pesticides and their metabolites are passed from organism to organism in a food web. The pesticides involved in this process are relatively stable (64, 65).

Direct Uptake:

The distribution of pesticides in water influences the pathway of biological uptake. Algae, higher plants, and invertebrate and vertebrate animals sorb large amounts of pesticides from the water and the sediment. The quantity accumulated by each biological entity is dependent upon the physiology and behavior of the organism, the chemical characteristics of the pesticide, and the seasonal periodicity in the quantities of pesticide available within a given aquatic habitat.

Plant

Algae are the primary producers in the aquatic environment. Grazers and higher consumer organisms depend upon algae as a food source, either directly or indirectly. Therefore, any accumulation of a toxicant by algae constitutes a potential hazard to consumer organisms (66).

Filamentous algae may accumulate very large amounts of chlorinated hydrocarbons (67). The accumulations of dieldrin by benthic algae and the influence of current velocity, light intensity and difference in algal community structure have been studied in laboratory streams (66). Dieldrin concentrations, ranging from 0.05 to 7.0 ppb (parts per billion), were maintained in the laboratory streams of natural water for periods of 2 to 4 months. Algal samples were found to contain dieldrin concentrations ranging from 0.1 to 100 milligram per kilogram (mg/kg) dry weight. Algal concentrations of dieldrin were as much as 30,000 times those occurring in the water. The physical factors studied had little effect on dieldrin accumulation but did, however, exert a strong influence on the species composition of the algal communities. This indirect influence can affect accumulation. Communities dominated by filamentous algae accumulated greater amounts of dieldrin that did those in which unicellular diatoms were dominant. Extensive pesticide sorption by select algal communities constitutes a contaminated food source for animals which feed on these forms.

Invertebrates

Daphnia magna is a planktonic crustacean. Daphnia concentrated DDT 16,000 to 23,000-fold during exposure to 8 ppb for 24 hours (68). The initial rapid uptake was principally through the carapace. The DDT level in the living Daphnia reached 75 percent of its final value within one hour.

Organic particulate matter of estuaries is an important food source for benthic organisms. In areas where most of the primary production occurs through the slow bacterial decomposition of such plant materials as marsh grasses, rushes and mangroves, a release of pesticide residues to the water may occur. This decaying plant detritus becomes an enriched food source when utilized by other microorganisms. DDT and its metabolites in the Carmans River marsh of New York (69) were most abundantly associated with particles of 250 to 1000 micron diameters. These detritus particles are ingested by consumer organisms and, in this way, enter diverse food webs. The mud dwelling fiddler crab concentrated DDT residues in its muscle tissues after consumption of detrital food material from sediment (69). Polychlorinated biphenyls, PCB, are biologically mobilized in this way. Aroclor 1254 contaminated sediments from Escambia Bay, Florida, were placed in separate aquaria containing local, uncontaminated populations of the adult pink shrimp and shore burrowing fiddler crabs (70). Both species accumulated aroclor 1254 in their tissues by ingesting contaminated sediment particles or by absorbing the leached chemical through their gills. Tissue concentrations were directly related to the amount of aroclor 1254 contained within the sediment (61.0 ppm, dry wt.) (71).

Oysters extract nutrition from the aquatic environment by filtering particles of food from the water which is continuously passed in and out of their bodies. The organisms accumulate pesticide contaminated particles in this fashion. Oysters efficiently store trace amounts of pesticides. Uptake rates and retention were studied in molluscs (72). The oyster is used as an estuarine monitoring organism by the Bureau of Commercial Fisheries at Gulf Breeze, Florida (73). High river stages and seasons of maximum pesticide usage in drainage basins correlate with peak residue levels in oysters (73). Oysters provide a sensitive index of the initiation, duration and extent of chlorinated hydrocarbon pollution in an estuary. The concentration or elimination of residues in oysters is dependent upon the level of pollution, the water temperature and their position relative to the water flow. To eliminate DDT residues of 150 mg/kg may require 3 months or longer while residues of less than 0.1 mg/kg may disappear in about two weeks. Fresh water mussels and crayfish are filter and substrate feeders, respectively, that concentrate high levels of pesticides (74).

It can be concluded that:

- Daphnia, an important fish food organism, concentrates DDT rapidly upon exposure to low concentrations in solution.

- DDT and its metabolites are associated with organic detritus especially in particle sizes ranging from 250 to 1000 microns.

- Detritus feeders concentrate DDT and PCB's from the sediment. PCB's accumulate biologically in concentrations approximately equal to sediment concentrations.

- Pesticide monitoring of certain sedentary, filter feeding organisms is useful in assessing the degree of chlorinated hydrocarbon pollution in a given habitat.

Vertebrates

The pathway of endrin entry into freshwater fish has been investigated. The mosquito fish and the black bullhead accumulate endrin directly from solution (75, 76). The principal mode of entry into the black bullhead is via the gill surfaces.

Accumulation and elimination of pesticide residues occurs in certain freshwater and estuarine fish. Small bluebills and goldfish were exposed to 0.3 mg/l concentrations of C^{14}-tagged DDT, dieldrin and lindane for 5 to 19 hours. The fish were then rinsed with uncontaminated water and placed in pesticide free aquaria. Lindane was eliminated from both species of fish within two days. More than 90 percent of the dieldrin was eliminated in the first two weeks. Less than 50 percent of the DDT was eliminated after 32 days. The DDT and dieldrin were readily transferred from contaminated to uncontaminated fish in the recovery aquaria (77). Similar experiments were performed using pinfish and croakers collected from an estuary near Pensacola, Florida (78). Each species was exposed to p,p'-DDT at 1.0 mg/l for two weeks or 0.1 ug/l for five weeks under dynamic test conditions. In the latter case, the fish were placed in pesticide free water for eight additional weeks after exposure to establish elimination rates. Pinfish and croakers exposed to 0.1 mg/l DDT accumulated a maximum DDT concentration of 10,000 to 38,000 times the aqueous concentration in two weeks. This concentration remained constant thereafter. After eight weeks in pesticide free water, pinfish and Atlantic croakers lost 87 and 78 percent DDT respectively. There was no increase or decrease in body concentrations of the metabolites DDD or DDE. However, fish from the estuary usually contained as much DDD and DDE as DDT. This indicates that fish from the estuary obtained the pesticide either after it had been metabolized and passed through the food chain or that DDT was rapidly metabolized within the fish.

The uptake, retention and release of organophosphates and herbicides by fish has also been studied. Malathion can be directly absorbed by carp (79). Uptake from exposure to 5 mg/l of malathion was time dependent for a period up to four days. Subsequently, equilibrium conditions were established. The equilibrium concentration was 28 mg/l. The greatest malathion concentrations were found in the liver but were degraded within a week following exposure. Uptake occurred primarily through the gills.

The uptake and release of the herbicide, simazine, by green sunfish, was measured after exposure to contaminated water and food (80). Fish absorbed simazine in amounts directly proportional to the concentration in the water. Simazine residues were completely eliminated from fish after seven days in freshwater, but little or no simazine was found in the tissues of fish 72 hours after feeding. The residue which was detected occurred in the viscera.

Fish can readily take up pesticides via the gills and an equilibrium is established between the body and water concentrations. Simazine can be accumulated in higher concentrations by direct absorption than through contaminated food pathways. However, DDT metabolites, measured in fish taken from estuaries, are at much greater concentrations than those in fish exposed to DDT within the laboratory. This indicates that substantial quantities are acquired from food chain organisms. Chlorinated hydrocarbon residues are stored, whereas, organophosphates are metabolized within a few weeks to a month. Species differences reflect varying storage ability. For example, pinfish stored 2.4 times as much DDT as croakers when both were exposed to 0.1 ug/l DDT. The elimination of stored pesticides from previously contaminated fish moving into uncontaminated waters, may render these residues available for uptake by uncontaminated fish.

Indirect Uptake: Plant-Animal Chain

The primary producers in aquatic food chains are bacteria, phytoplankton, periphyton and aquatic macrophytes. They can accumulate pesticide residues and provide food for herbivorous animals. Thus, the pesticide residues become biologically transferred and are magnified as they are passed from plant to animal.

Bacteria are nutrient regenerators, which serve as food for filter-feeding aquatic organisms. A common shallow-water marine bacterium, *Pseudomonas piscicida*, was subjected to various levels of DDT and malathion (65). The bacterium exhibited no alterations in growth rate or morphology when exposed to 10 mg/l labelled DDT or 100 mg/l of malathion. DDT uptake was rapid in a medium containing 1.0 ug/l (90 percent uptake in 24 hours). The DDT was found localized in the cell wall, whereas, the metabolites DDD and DDE occurred in greater concentration inside the cell. An artificial food chain has been established using this bacterium as the primary link. In addition, filter-feeding oysters and pipefish represented higher consumers. DDT was converted to its metabolites, DDD and DDE, during progression through the degradation forms. Conversion of the parent compound to its metabolites is significant and may explain the high levels of DDT occurring in terminal food chain members (birds and mammals) of natural ecosystems. A similar conversion with metabolite storage could occur with other chlorinated hydrocarbons. However, such metabolites have not been identified, "in situ."

Malathion has a half-life of 55 days in water at pH 6 and four to five days at a pH of 8 (65). *P. piscicida* maintains a high pH 9.5 in its surrounding microenvironment. It was proposed that malathion was rapidly hydrolyzed in this fashion. Rapid degradation was checked by allowing the bacterium to hydrolyze malathion in phosphate-free water for 48 hours. After that period, the bacteria were removed and algal cells (*Chlorella sp*,) were introduced. An untreated malathion solution served as a control. Twenty-five percent more algal cells were noted in the bacterially degraded solution than in the solution containing malathion alone.

Pesticides can affect natural populations of food chain organisms through inhibition of cell division, photosynthesis and growth. Concomitantly, this reduced food source would be reflected in reduced consumer populations.

The gonads of the mullet have been found to contain concentrations of DDT ranging from 3 to 10 mg/kg. The bottlenose dolphin feeds extensively on mullet and further concentrates the pesticide. Blubber samples of beached, dead dolphins were found to contain up to 800 mg/kg DDT. Whether or not DDT was the cause of death was not determined (81).

The transfer of persistent pesticides from plants to animals is of importance in an ecosystem. Direct toxicity to the primary producers or indirect toxicity to consumers may occur when the latter feed on producer organisms which concentrate pesticides. Either form of toxicity will reduce consumer populations. Eventually decomposers convert the biological material of higher trophic levels into inorganic products. These products then become available for production of organisms. Persistent pesticides could be recycled in this fashion for many years.

Animal - Animal Chain

Certain aquatic organisms assimilate pesticides directly from, and establish an equilibrium concentration with, the environment. Oysters establish equilibrium with the water concentration and eliminate body concentrations of DDT when placed in waters free of DDT (81). Similar observations have been recorded with certain freshwater fish (82).

The body concentration does not decline in organisms continuously exposed to chlorinated hydrocarbons once equilibrium has been established. The organisms pass the stored pesticides on to their consumer. The actual quantity accumulated varies with the pesticide. *Daphnia* containing DDT or methoxychlor were fed to guppies to complete a food chain (82). DDT was rapidly concentrated in the fish to about 8 mg/kg in 20 days while methoxychlor never rose above 0.17 mg/kg. Feeding midge larvae and tubificid worms, containing accumulated dieldrin, to the reticulate sculphin, produced similar results (83). Methoxychlor appears readily degradable in certain fish. Snails metabolize neither DDT nor methoxychlor but accumulate both to high levels (82).

The food chain pathways and biodegradation of persistent pesticides (DDT, DDE, DDD, and methoxychlor) have been studied in a model ecosystem (84). Terrestrial and aquatic components were involved. *Sorghum* was the terrestrial factor to which DDT was applied. Food chain pathways for the labelled pesticide in the system were:

Sorghum to *Estigmene* larva (salt marsh caterpillar)
Estigmene (excreta) to *Oedogonium* (alga)
Oedogonium to *Physa* (snail)
Estigmene (excreta) to *diatoms* (4 species)
diatoms to *plankton* (9 species)
plankton to *Culex* (mosquito larva)
Culex to *Gambusia* (fish)

The fate and conversion of DDT to stable and persistent DDE has been assessed. The application rate of C^{14}-labeled DDT corresponded to one pound per acre. One month after application to *Sorghum*, 52 percent of the radioactivity had been transferred into the snail, 58 percent into the mosquito larvae, and 54 percent of the radioactivity in the fish was DDE. This indicated that DDT had been metabolized to DDE. In the fish, DDE was present at a concentration of 110,000 times and DDT at 84,000 times the water concentration, respectively. These accumulations by the fish occurred in three days. Methoxychlor was rapidly degraded and very little reached the fish. However, the snail *Physa*, stored large amounts thereby indicating that it was unable to metabolize methoxychlor. Biomagnification of DDT and its residues, DDE and DDD, have been substantiated in natural ecosystems, food chains and food webs (85, 86, 87).

During the period 1964 to 1966, a total of 133 samples of coastal oysters from South Carolina, Georgia, Florida, Mississippi, Louisiana and Texas were analyzed for pesticide residues (88). Ninety-four percent of the oysters contained one or more pesticides; 89.5 percent contained two or more; 81.2 percent contained three or more; 63.9 percent contained four or more; and 31.9 percent contained five or more. The most frequently observed pesticides were DDE (123 of 131 samples), DDT (117 of 131 samples), DDD (81 of 81 samples), BHC-lindane (55 of 133 samples) and dieldrin (54 of 115 samples). The concentration of the individual pesticides was low. The median values ranged from 0.01 mg/kg for aldrin, chlordane, endrin, heptachlor, heptachlor epoxide and methoxychlor to 0.08 mg/kg for toxaphene, when present. BHC-lindane had a median value of 0.01 mg/kg. The median values for DDD, DDE and DDT were 0.02 mg/kg. Although not stated, the total concentration of the combined pesticides could have been important. The presence of pesticides in the oysters correlated with spraying operations in areas adjacent to the estuaries.

Estuaries are the primary breeding ground and nursery areas of many oceanic species. Any pesticide accumulated by these species during their inshore activities will subsequently be carried to the ocean. Fish, e.g., menhaden and sardines, feed in the estuary, and then move offshore where they become subject to predation by pelagic fish and birds. In this way coastal dwellers can pass substantial concentrations of pesticides to higher trophic forms of the open ocean.

Impact of Pesticides on Aquatic Populations

Populations of aquatic organisms exhibit both short- and long-term effects upon exposure to pesticides. Short-term effects include: immediate kills, reduced activity, loss of equilibrium, and paralysis. Long term effects include: population resistance, elimination of prey or predator organisms competitive ability and alteration of breeding patterns.

Short-Term Effects

Organomercurial fungicides in concentrations as low as 0.1 ug/l have been shown to reduce photosynthesis in lake phytoplankton isolates from Florida (89). Plankton were exposed to four different commonly used organomercurial fungicides in concentration varying from 0 to 50 ug/l. Diphenylmercury was least toxic. One ug/l of phenylmercuric acetate; methyl mercury dicyandiamide; and N-methylmercuric-1,2,3,6-tetrahydro-3, 6-methano-3,4,5,6,7,7-hexachlorophthalimide (MEMMI) caused a significant reduction in photosynthesis and growth of each culture. At 50 ug/l, uptake of inorganic carbon ceased.

The green alga, Scenedesmus quadricaudata, has been treated with diuron; carbaryl; 2,4-D; DDT; dieldrin; toxaphene; and diazinon. Diuron and carbaryl induced the most pronounced effects. Dramatic reduction in cell numbers and biomass occurred at concentration of 0.1 mg/l. Cell density was reduced in four days after treatment with 0.1 mg/l of 2,4-D. DDT, dieldrin and toxaphene reduced cell numbers at all treatment levels (0.1-1.0 mg/l) within two days of application. Diazinon was the only compound tested that had no effect on cell numbers, biomass or carbon uptake (90).

Four species of coastal oceanic phytoplankton, representing four major classes of algae, were subjected to doses of DDT ranging from 1 to 500 ug/l. Photosynthetic activity of diatoms was measured by carbon uptake. All species exhibited reduced carbon uptake with exposure to less than 10 ug/l of DDT. Complete uptake inhibition occurred at approximately 100 ug/l (91).

In one test the marine diatom, Cylindrotheca closterium, was exposed to the polychlorinated biphenyl, aroclor 1242. The diatom absorbed and concentrated the chemical 900 to 1,000 times that of the water. This PCB inhibited growth at 0.1 mg/l and decreased levels of RNA and chlorophyll synthesis. (92).

The herbicide, 2,4-D, reduced the cell density of the green freshwater alga, Scenedesmus (35). The Gulf Breeze Laboratory of the Environmental Protection Agency in Florida measured no alteration of photosynthesis in 7 of 9 species of unicellular, marine algae when exposed to concentrations of 0.1 to 10 mg/l of purified 2,4-D (93). In 2 of 9 species photosynthesis was enhanced. Therefore, different algal species respond differently to specific pesticides. Information is needed to determine whether this is a result of different environmental conditions or is a basic genetic difference. Even in very small doses, the quality and the quantity of the basic food chain populations, (the phytoplankton) were adversely affected by pesticides.

Tetrahymena pyriformis cultures have been exposed to DDT from 0.1 to 10 mg/l (94). Growth decreased with increasing concentrations of DDT. Populations were reduced by 13.8 percent at 0.1 mg/l, 20.2 percent at 1.0 mg/l, and 25.7 percent at 10 mg/l. T. pyriformis is more sensitive to DDT than Paramecium multimicronucleatum and P. bursaria .

The respective lethal concentrations to marine invertebrates (crab, shrimp and oyster) of specific pesticides are known (95, 96). The chlorinated hydrocarbons are toxic to fish and molluscs at concentrations as low as 0.001 mg/l. Organophosphates have a pronounced effect on crustaceans at equally low levels (97). Insecticides, as a group, are more toxic in low concentrations than are other pesticides, with two exceptions. The fungicide, delan and an experimental antifouling arsenical, ET-546, are extremely toxic to oysters at 2.1 ug/l.

Mirex has a delayed effect on crabs and shrimp. Juvenile blue crabs and pink shrimp exhibited no adverse symptoms during a 96-hour exposure to 0.1 mg/l technical mirex (98) but became paralyzed and died within 18 days. Similar paralytic effects have been demonstrated in freshwater crayfish (99). Juvenile Procambarus blandingi and P. hayi, of Louisiana and Mississippi were exposed to 1 to 5 ug/l mirex for periods varying from 6 to 144 hours, transferred to clean water and observed. Mortality reached 100 percent within 5 days for P. blandingi following a 144 hour exposure to 1 ug/l of mirex. Exposure of P. blandingi to 5 ug/l for 6,24, and 58 hours, yielded 26, 50, and 98 percent mortality, respectively, 10 days after the initial exposure. A greater sensitivity of mirex was observed in P. hayi than P. blandingi. Delayed mortality occurred in all tests.

The polychlorinated biphenyl, aroclor 1254, merits attention because it is similar to chlorinated hydrocarbons in its persistence and lethality to certain aquatic organisms once it enters waterways. Laboratory studies in Florida have demonstrated that juvenile shrimp are killed upon exposure to 5.0 ug/l of this PCB (99). Adult shrimp taken from an estuary contained a maximum of 2.5 mg/kg of the PCB. Gammarus oceanicus, exposed to 0.001 and 0.01 mg/l of the PCB for 150 hours died and had branchiae with severe necrosis (100).

The amphipod, Hyalella, was found to be highly sensitive to diquat (101). The 96-hour mean TLm (median tolerance level) value was 4.8 ug/l. Immature stages of aquatic insects; dragonflies, damselflies, midges, mayflies, and caddisflies had 96 hour mean TLm values of >100, >100, >100., 33.0, and 16.4 mg/l respectively.

The seed shrimp were completely immobilized within 48 hours by 4 and 54 ug/l of DDT (102). The TL-50 (concentration at which 50 percent of a population survives) values for the damselfly and the scud were 22.5 and 3.6 mg/l, respectively, in 48 hours. The TL-50 in 24 hours for the fathead minnow and the channel catfish was 24.6 and 25.8 mg/l respectively.

Investigations of fish kills in Alabama are made by the Water Improvements Commission and State Department of Conservation (103). In 1967, 21 fish kills were reported in the state; 4 of these were attributed to agricultural insecticides. In 1968, 48 fish kills were reported. Three were caused by agricultural insecticides, one in the Lower Tombigbee River and two in the Tennessee River. The specific insecticides and their sources were not reported.

Long-Term Effects:

Chronic toxicological effects are elicited in an organism as a consequence of continuous or repeated exposure to low-level concentrations of pesticides. The time span involved may range from weeks to years. Chronic effects are dictated by the degree of exposure and by the fate of pesticide residues within the animal. If the degree of exposure is greater than the capacity of the animal to detoxify and eliminate the residues, a toxicity hazard exists. This is particularly important when pesticide effects are additive or when residues are temporarily stored in tissues (64). If the interval between exposures is insufficient to allow for complete purging, then toxic effects become additive. If uptake rates exceed those of degradation and elimination, excess fat soluble residues may accumulate to high levels. Such accumulations may cause toxic effects when fatty tissues are mobilized. Stored residues of a given concentration may not produce demonstratable toxic effects in the directly exposed animal but may induce toxic effects after being passed and magnified at higher trophic levels.

Population Changes

Long-term population and ecological changes are subtle and less obvious than acute effects. Causal factors may be just as subtle and difficult to identify and assess. Animal populations can be indirectly affected by pesticides through reduction in food supply. The productivity of phytoplankton (basic food organisms) can be reduced by exposure to very small amounts of pesticides. Species of estuarine phytoplankton, isolated in the Southeast were exposed to chlorinated hydrocarbons in four hour controlled tests (104). Aldrin, chlordane, DDT, dieldrin, heptachlor, methoxychlor, and toxaphene, each at a concentration of 1.0 mg/l, reduced productivity by 28 to 64 percent. Exposure of plankton to herbicides has reduced productivity to a highly variable extent (95). The concentrations necessary to induce significant inhibition far exceeded expected concentrations in the open ocean and exceeded by ten times the solubility of DDT (ug/l) in water (105).

Effects of long term, low level concentrations of pesticides on plant populations are not known. Aquatic plants function ecologically by producing food and oxygen and by serving as spawning areas and substrates for other organisms (106). Increased herbicide usage poses a threat to the stability of estuarine ecosystems which support shrimp, fish and shellfish. In Florida two natural coastal ponds were used (106) to determine an aquatic ecosystem response when rooted plants were eliminated. Dichlobenil was injected beneath the water surface to achieve a concentration of 1.0 mg/l in one pond; the other served as a control.

The ponds were without tidal effects. Physical factors such as sunlight, air temperature, wind speed and organism behavior were measured. Dissolved oxygen, pH, nitrates, dissolved carbohydrate, salinity and chlorophyll A were monitored. Gross algal primary production was determined by light- and dark-bottle techniques. Both pond basins were approximately one meter in depth. Bottom substrata were composed of sand and fine matter. Chemical and physical parameters of the two ponds were similar prior to treatment. One month after treatment, Potamogeton and 80 percent of the Chara were eliminated. An intense bloom, dominated by blue green algae, developed. This was attributed to the release of nutrients from decomposing vascular plants. Concentrations of phytoplankton chlorophyll rose to 29.3 mg/l after herbicide application, but fell sharply during the period of vascular plant recovery. Phytoplankton produced over 90 percent of the dissolved oxygen during the period of rooted plant absence but resumed a secondary role after vascular plant recovery. The herbicide had disappeared from the water and hydrosoil 64 days after application. Residues did not persist in the organisms and the degradation product, 2,6- dichlorobenzoic acid, was not detected (107). This study has shown that subtle ecological changes can occur when pesticides are introduced into the aquatic environment. Factors operating over the long term may result in trophic population alterations. For example, a population change from carnivorous to phytophagus fish species as terminal members could result from a shift in the populations of lower food organisms. Such a change would be reflected in increased numbers of plankton feeding mullet, in an estuarine environment (106).

Small blue crabs, Callinectes sapidus, live in shallow estuarine waters where they may be exposed to chronic sublethal concentrations of pesticides. Test crabs fed, molted and grew for nine months in seawater containing 0.25 ug/l DDT but survived only a few days at concentrations in excess of 0.5 ug/l (108). This suggests that the threshold of toxicity is very critical. Populations that can exist in estuarine waters containing low levels of DDT may be seriously affected by sudden, moderate increase, such as those produced by runoff.

In two separate chronic exposure tests, immature oysters, Crassostrea virginica were first exposed to 1.0 ug/l concentration of DDT, toxaphene and parathion for 48 weeks. In the second test, the oysters were exposed for 36 weeks to a mixture of all three of the pesticides at a total concentration of 3.0 mg/l (109). Relatively high levels of DDT and toxaphene were accumulated but only small amounts of parathion were found. The immature oysters grew to sexual maturity in flowing seawater in both of the tests, but their weights were 5 percent lower than control oysters. No statistical difference in the weights of oysters grown in solutions of the individual pesticides and the controls were found. Histopathological damage was found in the kidney, visceral ganglion, gills, digestive tubules and tissue beneath the gut in the oysters exposed to the mixture of pesticides. The presence of a mycelial fungus indicated a breakdown in the oysters natural defense against this parasite. These changes were not observed in the oysters exposed to the individual pesticides. It is concluded that although oysters can survive and grow in a low concentration mixture of pesticides, subtle pathological changes can be induced. Such changes reduce the ability of the organism to survive under competitive pressures. It was not established in this study whether these changes resulted from a synergistic interaction of all three pesticides in combination or from their additive effects.

Chronic exposure to sublethal concentrations of pesticides elicits three observably different population responses in fish, i.e., an adverse effect on population size and number, no demonstratable effect, or an acquired resistance (110-120). Adverse effects on populations have been observed as changes in mortality or growth rates. Mortality rates among populations of fish subjected to sublethal doses of chlorinated hydrocarbons have been found to be proportional to the magnitude of dose. Dose-dependent mortality has also been observed in the freshwater sailfin molly (Poecilia latipinna) exposed to dieldrin. More than half the experimental fish survived 1.5 and 0.75 ug/l dieldrin but showed a 10 percent decrease in growth after 34 weeks. However, 0.012 mg/l dieldrin killed all exposed fish within the first week (111). Similar dose-dependent mortality and growth responses have been observed in goldfish and bluegills upon exposure to mirex (112) and in spot fish, Leiostomus xanthurus, upon exposure to endrin (113). Offspring of a population of sheepshead minnow, Cyprinodon variegatus, which survived chronic sublethal concentrations of DDT, were found to be more sensitive to DDT and endrin than were offspring of unexposed, control fish (114). No observable pathological changes were reported for the continuous exposure of the spot fish to sublethal endrin concentrations (0.05 ug/l) for 8 months (113). However, these same fish were further tested to determine whether sublethal exposure to endrin had affected their resistance to acute toxic concentrations (0.75 and 0.56 ug/l) of endrin. They were less tolerant than controls during the first 24 hours of exposure (113). A similar increased sensitivity of response was observed with the same fish during chronic exposure to toxaphene (115). No effects on growth or mortality of the spot fish were observed when they were subjected to 10 ug/l concentrations of malathion for 26 weeks (116). This may be attributed to the rapid detoxification of the organophosphate in seawater. One week after the termination of the chronic exposure test, the same fish were subjected to lethal concentration of malathion. However, differences in mortality rates between control and test fish were not significant. Fish that survived chronic toxicity testing were further stressed by placing them under reduced salinity conditions (from 25 percent salinity to 2.8 and 1.5 percent). No effects were observed between test and control fish (116).

Development of resistance to chlorinated hydrocarbons, following long-term exposure, has been demonstrated by freshwater fish (117). Once resistance is acquired by fish, the level remains unchanged for several generations if they are reared in insecticide free environments (117). Resistance to high pesticide concentrations was first noted in mosquito fish localized in heavy cotton producing areas of the Mississippi Delta. Two thousand-fold levels of resistance have been acquired by fish in this area (118). Resistant populations of Lepomus macrochirus have been obtained from pond and ditch areas in the Mississippi Delta (117, 119-120). These areas bordered large cotton plantations and were subject to contamination by run-off, spray drift, and possibly, direct application (115, 117). Resistance was demonstrated when the fish were exposed to the TLm concentration for DDT, toxaphene, aldrin, dieldrin, and endrin. The fish from the Twin Bayou area of the Delta, as compared to control populations taken from non-agricultural areas, were resistant to all test insecticides except DDT (117). These fish exhibited resistance to endrin, one of the most toxic insecticides to freshwater fish, at levels approximately 50 fold greater than those which would affect controls. The fish communities from which these populations have been taken are represented by large numbers of a few species (118). Top level carnivores, such as large mouth bass or crappie were absent.

Population resistance is not limited to fish (121). Freshwater shrimp, P. kadiakensis, from three areas of the Mississippi Delta were up to 25 times more resistant to seven chlorinated hydrocarbons, 3 organophosphates and 1 carbamate than were non-resistant control shrimp (122).

Pesticide resistance and accumulation by non-target organisms in the aquatic environment has caused community structural imbalance (118). Top-level carnivores, such as the largemouth bass, egrets, and gar, are absent in waters supporting pesticide resistant populations. Resistant strains of the mosquito fish can tolerate a body burden of 214.18 mg/kg after two weeks exposure to 500 ug/l endrin. When placed in fresh tap water these fish released endrin in sufficient concentration to kill green sunfish in 15.5 hr. (123). Adaptive physiological mechanisms that produce resistance in fish and shrimp have not been identified (118). Resistance in a species may occur via alteration of membrane permeability, increased fat content, or altered metabolic pathways.

Physiology and Reproduction

Organophosphate pesticides inhibit the enzyme, cholinesterase, which is functional in nerve impulse transmission and ion transport processes (124, 125). Tests on the sheepshead minnow relate acute toxicity of diazinon, guthion, parathion and phorate to *in vivo* inhibition of brain cholinesterase (124). Adult minnows were exposed to acute doses which killed 40 to 70 percent of the fish in 24 and 48 hours, respectively. The enzymatic activity of exposed fish was compared to that of control fish. The number of fish killed by each organophosphate was proportional to cholinesterase inhibition. The average level of cholinesterase inhibition in the brain of fish does not always correlate with the percentage of fish killed by a particular pesticide (124, 126). Differences within and among populations of fish indicate that cholinesterase activity of a species fluctuates with time (126). Some organophosphates increase in toxicity with time. For example, parathion can be converted in the liver of certain fish to the more toxic paraoxon, thereby increasing toxicity (127).

Specific physiological modes of action by chlorinated hydrocarbons are not known. It has been shown that DDT impairs osmoregulation (128) and active membrane transport (129). These mechanisms require cholinesterases (ATPase). Chlorinated hydrocarbons, including DDE (105) and PCB (130) induce mixed function oxidases. These enzymes are functional in metabolizing steroid hormones, such as estrogen and testosterone. Numerous general observations on the impairment of motor and sensory systems by sublethal concentrations of chlorinated hydrocarbons have been reported (119, 120, 131). Symptoms indicate central nervous system disorders including convulsions, loss of equilibrium, increased ventilation rate, hyperactivity and hypersensitivity to stimuli.

Although exact mechanisms of pesticide toxicity are unknown, certain structural abnormalities in tissues and organs are associated with pesticide presence. Nimmo and Blackman (132) of the Gulf Breeze Laboratory, have shown that exposure of pink shrimp to a sublethal concentration of DDT (0.1 ug/l) produces blood protein alterations. Preliminary studies demonstrated a decrease in serum protein levels of up to 41 percent after 45 days of exposure. Follow-up experiments are being conducted to determine if a "threshold" concentration is reached prior to this observable gross effect. Chronic pesticide exposures produce blood changes in the marine puffer fish (133). Endrin caused an increase in serum sodium, potassium, calcium and cholesterol.

Chronic exposure to chlorinated hydrocarbons induces systemic lesions and other structural disorders. Gill changes in goldfish, characterized by swollen filaments, appeared 112 days after an initial concentration of 1.0 mg/l mirex was applied to a pond (112). Chronic exposure of spot fish to 0.075 ug/l endrin for three weeks produced systemic lesions throughout the brain, spinal cord, liver, kidneys and stomach (113). Lesions of the central nervous system, kidneys and stomach were attributed to primary effects of endrin. It was probable that necrotic liver lesions were also attributable to systemic toxicity. The appearance of lesions offers an opportunity for bacterial and fungal infections (109, 134). Exposure of pinfish and spot fish to sublethal (5 ug/l) concentrations of the PCB, aroclor 1254, over a maximum of 45 days produced pronounced fungus like lesions on the body (134) and hemorrhaging around the mouth. The affected spot fish usually ceased feeding, became emaciated, and developed frayed fins and lesions on the body. These exposure associated changes could significantly reduce longevity.

Dichlobenil caused karyolysis of hepatocytes and an increase in connective tissue stroma in the liver of bluegills (135). Chronic exposure of bluegills to 2,4-D caused rapid shrinkage and loss of vacuolation in parenchymal cells and a depletion of stored glycogen in the liver (110). These fish also exhibited a reduced circulation and simultaneous depletion of liver glycogen.

Blood stasis resulted from congestion of larger blood vessels in the central nervous system, gills, liver and kidneys. Congestion was caused by amorphous, eosinophilic deposits of serum protein precipitates. Histopathological damage, induced by chronic pesticide exposure, may or may not be related to function of a particular tissue. Knowledge is inadequate in tissue effect mechanisms of pesticide toxicity. Until these mechanisms are elucidated, the effects of pesticide induced histopathologies on survival of species in the natural environment cannot be understood.

Survival of a species depends on its ability to reproduce efficiently and maintain population size. Pesticides are known to interfere with this process (110, 119, 136). However, specific factors contributing to reproductive failure and the frequency and extent of their occurrence are not known. These factors can create subtle changes in population behavior (110). Exposure to 1000 ug/l solutions of dursban for a period of time sufficient to kill 50 percent of the test population, caused female mosquito fish to prematurely terminate gestation (119). Mosquito fish abortion has been induced by several chlorinated hydrocarbon insecticides (119). Exposure to dieldrin in concentrations of 0.075 and 1.5 ug/l for 34 weeks, caused the sailfin molly to produce fewer numbers of young (111). Populations of guppies showed a change in size-class distribution after 7 months exposure to 0.0018, 0.0056, and 0.01 mg/l of dieldrin. The greatest increase was in the number of young. This was attributed to decrease in cannibalism by the parent fish (136).

The presence of pesticides in an estuary could adversely affect the breeding behavior of resident crustacea and fish populations (136). In addition, breeding and migratory behavior of fish which spend only a portion of their life cycle in these fertile nursery grounds could be affected. For example, fish may avoid pesticide contaminated water and, thereby, be unable to reach proper spawning grounds. Some fish in Tennessee Valley Authority lakes moved out of the area when 2,4-D was applied for the control of Eurasian water milfoil (138). Avoidance behavior was demonstrated by the estuarine sheepshead minnow (139). These were subjected to water containing DDT, endrin, dursban, 2,4-D, malathion and sevin. Concentrations ranged from 0.0001 to 0.1 mg/l for DDT, 0.00001 to 0.01 mg/l for endrin, 0.01 to 10 mg/l for dursban, 0.01 to 1.0 mg/l for malathion, 0.1 to 10.0 mg/l for sevin and 0.01 to 10.0 mg/l for 2,4-D. The fish avoided four (DDT, endrin, dursban and 2,4-D) of the pesticides at the concentrations tested. They avoided neither malathion nor sevin. The fish did not appear to differentiate between differences in lower concentration of the same pesticide but displayed the ability to seek water free of pesticides. Therefore, a prerequisite for avoidance in nature would be a reasonably distinct boundary between clean and pesticide contaminated water and free access for migration. Estuaries are often characterized by conditions that create such boundaries or interfaces (139). There is evidence to suggest that DDT in estuaries may affect the migratory mechanism of certain fish. The greater the DDT concentration, the greater the preference for high salinity (140). This could interfere with spawning behavior since it suggests a tendency of fish exposed to pesticide pollution to return seaward.

The reproductive organs of aquatic organisms are major storage sites for chlorinated hydrocarbons (97, 141, 142). The gonads of the oyster stored approximately twice as much DDT as the digestive tract and other organs (142). The residues accumulated in such organs could directly affect gamete maturation and viability, cell cleavage, and vitality of the developing larvae. Fish store chlorinated hydrocarbons in the gonads and in the egg yolk (81). Pinfish and Atlantic croaker populations of Pensacola Bay lose an estimated aggregate of 1/2 lb. of DDT and metabolites during egg deposition (141). The DDT concentration of speckled seatrout in some areas of the Gulf average about 8 mg/kg (81).

Chlorinated hydrocarbon residues have seriously affected reproduction of adult water fowl. Eggshell thinning and consequent population decline have been attributed to chlorinated hydrocarbon residues (143, 144) - DDE concentrations as high as 2,500 mg/l have been found in the yoke portion of eggs with the thinnest shells (143). Dieldrin and endrin were also found in lesser amounts. DDT and DDE have been included in the diets of mallard ducks in controlled experiments. Thin eggshells and reduced mating success were observed. A nationwide survey was conducted to determine the chlorinated hydrocarbon residue levels in the mallard and the black duck (145). Alabama recorded the highest average level of DDE in the survey (2.17 mg/kg in wing samples). Dieldrin, lindane, and endrin were also found in varying amounts. Raptorial birds, such as the herring gull and the peregrine falcon, feed on birds, rodents, mammals and fish. Their populations are suffering a decline that correlates with observed eggshell thinning (146). In 1967, herring gull eggs were collected from five states (147). The shell thickness had decreased from 1947 to 1952 while chlorinated hydrocarbon residues had increased. Brown pelican eggshells from Florida and South Carolina (148) have shown significant thinning (16 to 17 percent decrease) as compared to pre-1947 indices and have shown a related decline in local populations.

Transport of ionic calcium across the membrane of the shell gland in birds is an energy requiring process dependent upon a specific enzyme (143). Inhibition by DDE could account for certain concentration effect correlations (DDE concentration vs. shell thickness) obtained for eggs of the brown pelican and herring gull. DDE, and PCB's have been found to inhibit carbonic anhydrase (143). The enzyme is functional in deposition of calcium carbonate in the eggshell and for maintenance of pH gradients across membranes such as those of the shell gland. Associated with eggshell thinning is the problem of increased egg eating by parents, decreased clutch size and increased embryonic mortality (149). The importance of PCB's to observed reproductive failures is unknown in species of birds that are known to accumulate high concentrations of these substances.

In summary, low level pesticide contamination of water systems produces subtle and complex changes of aquatic life as a result of chronic exposure. Physiological changes of individuals are reflected as long term changes in biotic community structure. In nature, such changes usually go unnoticed until a species considered desirable by man is threatened or eliminated. Waters of the United States are contaminated with pesticides, the extent of which depends on seasonal inputs. Concentrations are often greatest in estuaries during the spawning season of certain crustacea and fish (141). The level and persistence of DDT in Gulf estuarine fauna suggests that commercial species of shrimp may be endangered in certain sections (97). Information is needed regarding ecological alterations induced by chronic stress from pesticides in fresh and estuarine waters.

Synergistic Effects:

Synergism occurs when the simultaneous action of separate factors, operating together, produce effects greater than the sum of the effects of the separate factors. Through synergism, a pesticide may act with other pesticides or with other physical, chemical or biological factors to cause an adverse effect at concentrations far less than the toxic level of that substance acting alone. Anomalous laboratory results and field observations suggest that static conditions as opposed to dynamic ones were attributed to decreasing oxygen concentrations and/or synergism with fish-produced metabolites (e.g., ammonia or carbon monoxide). Assessing toxicity of pesticides, under static test conditions, can result in significant error (152). The pesticides could interact synergistically with numerous and varying physical and chemical factors of the aquatic environment. A greater emphasis must be placed on dynamic bioassay testing under natural conditions.

Certain chemical compounds have been shown to increase the toxicity of specific pesticides. Copper sulfate pentahydrate has been applied in conjunction with diquat to control hydrilla, egeria and southern naiad (153). This combined treatment yields better control than does individual application. Submersed plants absorbed more copper from pools containing both substances than from pools containing only CSP.

Pesticide activity may be enhanced by differing pH's. This may result from pH induction of hydrolysis products that are more toxic than the parent compound. The fathead minnow has been exposed to malathion under various pH conditions, the metabolic product, diethyl fumarate was formed. The metabolite was found to be more toxic in the presence of the parent compound than either substance acting alone. More information is needed on synergisms between parent compound and degradation products. Oysters exposed to a mixture of 1.0 ug/l each of DDT, toxaphene and parathion showed less growth and developed tissue pathology (109). Changes were not evident in organisms reared in 1.0 ug/l of either DDT, toxaphene or parathion. The results suggest that the effects may have been caused by a synergism among the three toxicants.

In summary, the abiotic environment can alter the effect of a pesticide by either increasing or decreasing biological uptake and activity. Physical and chemical factors of the environment must be considered in conjunction with pesticide usage.

Biological Synergisms

Mirex has been found to affect juvenile and adult crayfish differently (99). Mortality from treatment with 1 to 5 ug/l of Mirex for 6 to 144 hours increased with time and juvenile crayfish exhibited higher mortality rates than did adult crayfish. Juveniles about 1.5 cm long showed 55 percent mortality 3 weeks after consuming one granule of Mirex bait while adults of a 3.0 cm length showed no mortality.

Physical Synergisms

Temperature and pesticides may combine in a synergistic manner to adversely affect aquatic organisms. Through a temperature range which allows an organism to function, for each 10 degrees C. increase in temperature, the metabolic rate of an organism will increase. As temperature rises, dissolved oxygen concentration of the water decreases. Temperature effects may combine with pesticide action to increase toxicity. Oysters, for instance, are more sensitive to DDT and endrin at the same concentration during the summer than during the winter (142). The reverse is true of organophosphate compounds; these are hydrolyzed at lower rates in colder water (142).

Trout and bluegill have been exposed to the presence of pesticides and varying temperature (147). Increased susceptibility was observed with most compounds as temperature increased. Exceptions were noted for bluegill susceptibility to lindane and azinophosmethyl. Mosquito fish, golden shiner, bluegill and green sunfish were exposed to DDE, endrin, aldrin, dieldrin and toxaphene at different seasons of the year (117) and higher tolerance levels were found during March and April than during June and July. For example, green sunfish tolerance to endrin over 36 hours declined from 575 to 160 ug/l. A seasonal sensitivity to lethal concentrations of DDT and endrin has been noted in sheepshead minnows of Florida. Sensitivity to 15 mg/l of DDT decreased during colder months (March to June) and increased during warmer months of August and September (114).

Salinity has been tested as a synergist (151). Mosquito fish were acclimated at 0.15, 10 and 15 parts per thousand (ppt) salinity and DDT, DDD or DDD were introduced. A salinity of 15 ppt reduced the amount of DDT, DDE and DDD accumulated. DDT uptake was less than either DDE or DDD. DDT has been shown to impair the osmoregulatory system of the marine eel (128). This effect may explain reduced DDT uptake with increased salinity.

The fathead minnow was exposed to endrin or DDT under static and dynamic conditions (152). Comparative 48- and 96-hour endrin exposure indicated a slightly higher LC-50 value during static as compared with dynamic tests. The higher toxicity of endrin under static conditions was not explained. However, there was a sharp increase in toxicity of DDT three weeks after consuming one granule of mirex bait; adults of a 3.0 cm length showed no mortality. Increased toxicity to juvenile forms over a period of time was attributed to delayed toxic effects of mirex. Juvenile forms of other crustacean species frequently display greater mortality factors than do adult forms. This has been, and will continue to be, increasingly significant in the nursery areas of estuaries (97).

Amitrole, dalapon, endothall, fenuron, dichlobenil, dimethylamine salt of 2,4-D, isooctyl ester of 2,4-DP, and the potassium salt of silvex at various concentrations over varying lengths of time had no appreciable effects on hatching of fish eggs (bluegill, green sunfish, smallmouth bass, lake chub sucker and stone roller) (155). However, the fry were found to be more susceptible to the toxic action of some herbicides than were fertilized eggs. Concentrations greater than 5 mg/l of silvex and 10 mg/l of fenuron reduced the number of fry produced from fertilized eggs. Different formulations of some herbicides showed different toxicities. Endothall did not affect the fry at concentrations of 10 and 25 mg/l. Carp eggs have been exposed to DDT, chlordane, dieldrin, endrin, diazinon and guthion at a concentration of 1.0 mg/l (156). Embryo development was stimulated and the incubation time was reduced by one-third.

The egg stage of an animal can be relatively resistant to pesticides. The yolk material nourishes the developing embryo. Oxygen and water are obtained from the external environment. The offspring may not be exposed to pesticides until the yolk material has been depleted and/or hatching occurs.

Fingerling mosquito fish have been grouped into size-classes and exposed to 41 ppt concentrations of DDT (157). The smaller fish were more efficient in DDT uptake than were older fish within a 48 hour period. This was attributed to increased surface area to volume ratios in the smaller fish relative to those of larger fish. This relationship may be another factor that acts synergistically to alter toxicological effects.

Pesticide synergisms with such factors as temperature, pH, other pesticides, and stage of biological development have been established. Synergisms, resulting from multiple-pesticide usage, have not been investigated thoroughly. Static bioassays are likely to result in limited toxicity information that does not recognize synergistic effects. The results would be of little use in predicting the effect in natural systems. Dynamic, carefully designed tests are needed.

Health Implication of Pesticide Contaminated Water

The routes of pesticides from the contaminated water environment directly to man are limited. Potable water is the most obvious route. Less obvious is the route through consumption of pesticide contaminated food such as crabs, shrimp, fish and waterfowl.

Contamination of Potable Water Supplies

During 1962, DDT residues were found in the Tennessee and Chattachoochee Rivers, while dieldrin was reported in the Savannah River (158). A 1964 survey of 56 U. S. rivers revealed that 44 were contaminated with chlorinated hydrocarbons in concentrations ranging from 0.002 to more than 0.118 ug/l (159). Dieldrin occurred in 39, DDT or DDE in 25, and endrin in 22 rivers. Between 1964 and 1967 water samples were obtained from 10 selected municipal water supplies and analyzed for chlorinated hydrocarbons (160). Raw water sources for these systems were either the Missouri or Mississippi Rivers. One sampling site was located in Vicksburg, Mississippi, and of the 41 samples obtained here in 1964, four were positive for aldrin, 29 for DDE, 28 for DDT, 23 for dieldrin and 34 for endrin. The survey was expanded to monitor 5 additional pesticides in 1965. Lindane was present in 4 of 6 samples, BHC in 5 of 6, aldrin in 3 of 45, heptachlor in 1 of 24, HCE in 6 of 37. Chlordane was not detected in 6 samples. Ingestion of at least 9 known pesticides was involved in consumption of this water.

The Flint Creek basin of Alabama was monitored for pesticides between 1959 and 1962 (161). The entire 400 square mile basin is located in a predominately cotton producing area. Flint Creek and the West Fork of Flint Creek are the principal streams of the basin. A water treatment plant is located downstream from the junction of the forks and serves Hartselle and Flint, Alabama. Pesticide analyses of treated and raw water samples at the treatment plant revealed contamination by toxaphene and BHC. Treated water contained pesticide concentrations comparable to the raw water. DDT was not found although it was used extensively within the basin. BHC contamination was attributed to crop dusting in the basin. The concentration of pesticides reaching the public via drinking water was less than 1 ug/l.

Once pesticides reach water treatment plants, removal through conventional coagulation and sand filtration becomes selective (162). This is attributable to variations in solubility and adsorption. In one case, DDT at a concentration of 10 ug/l was effectively removed while lindane and parathion were not. The latter was presumably a result of greater water solubility. Chlorine treatment did oxidize parathion to its toxic derivative, paraoxon. Potassium permanganate at 1 to 5 mg/l and ozone at dosages up to 38 mg/l was ineffective. Powdered activated charcoal was of limited effectiveness in removing pesticides. Lindane reduction from 10 to 1 ug/l, required 29 mg/l carbon. Percolation through a bed of granular carbon was the most effective means of treatment, more that 99 percent of the applied DDT, lindane, parathion, dieldrin, 2,4-D, 2,4,5-T ester, and endrin concentrations were removed. Recent information indicates that occasional high pesticide concentrations may be reduced to acceptable levels by standard water treatment practices (163). However, chronic, low level concentrations are difficult to remove by current practices. At present, removal of pesticides from large bodies of water is economically unfeasible (164). Therefore, long periods will be required for renovation by natural processes. This will be facilitated as persistent pesticides are replaced by more readily degradable compounds.

Ingestion via Food Products

The main source of general population exposure to DDT and dieldrin occurs via ingestion of residues in food (165). Residues of DDT and its metabolites have been reported in processed fisheries products (fishmeal, oyster, and shrimp). These residues ranged from 0.02 to 0.063 mg/l (166). Game fish from 9 monitoring stations in the Southeast contained chlorinated hydrocarbons (166). Channel catfish of the St. Lucie canal in Florida and largemouth bass from the Tombigbee River in Alabama contained 58 mg/l and 10 mg/l of DDT and its metabolites, respectively. These levels were greater than those generally reported for other species of fish in other locations. These results were obtained from whole body samples and not exclusively from edible portions. Chlorinated hydrocarbons accumulate in the fatty tissues of fish. Once fish are processed for consumption, most of the pesticides generally remain with discarded visceral portions. Shrimp primarily accumulate pesticides in the non-consumed hepatopancreas. Oysters concentrated pesticides in their tissues to levels thousands of times greater than the water concentration. These tissues are normally cleansed of pesticides within a short period if placed in uncontaminated water. Therefore, oyster harvests that are contaminated by pesticides can be decontaminated prior to marketing by placement in clean water.

With the exception of BHC, six of seven pesticide residue levels in domestically processed seafood for the years 1964 to 1969 exceeded those of imported products (167). Domestic fish products contained 74.4 percent of chlorinated hydrocarbon residues compared to 56.1 percent for imported varieties. DDE was present in 66.3 percent of the domestic varieties at an average of 0.49 mg/l and in 49.1 percent of the imported varieties at an average of 0.06 mg/l. Heptachlor, heptachlor epoxide, aldrin and chlordane were not found in imported shellfish products. DDE ranked highest in terms of incidence and averaged 0.005 mg/l. Forty-eight percent of the domestic shellfish products contained chlorinated hydrocarbon residues as compared to 16.8 percent for imported products. The higher concentrations in domestic seafood probably result from the fact that more agricultural pesticides are used in the United States than in any other country. Therefore, larger amounts are deposited by runoff in streams and rivers. These are eventually deposited, in part, into estuaries and become available to estuarine organisms.

The effect of human ingestion of DDT over a two year period has been determined (168). Ninety men were divided into three groups: one group received no DDT, another received 3.5 mg/man/day, and the last received 35 mg/man/day over the two years. The dosages were established at 20 and 200 times the normal dietary intake level for DDT. The highest dosage was chosen to represent one-fifth of the smallest amount known to cause mild, transient sickness in man. Careful physical examination and laboratory testing failed to establish clinical evidence of adverse effects. DDT was confined to the body fat and was proportional to dosage. About one year was required to establish constant tissue storage levels of 234 to 340 mg/kg. Tissue biopsy examination revealed no further increase in storage level once equilibirium was attained. DDT release from body fat was a much slower process than its deposition. The storage form was DDE.

Prolonged occupational exposure of an individual to DDT has been reported. A storage level of 64.8 mg/kg of DDT and its metabolites was established (169). The individual exhibited no adverse effects.

Autopsies of 146 persons included measurement of dieldrin storage in adipose tissue. A range of 0.19 to 0.24 mg/kg was obtained when samples were grouped according to age, race and sex (170). This level was not statistically different from results obtained in other parts of the world. World wide distribution fell into a range of 0.15 to 0.29 mg/kg. However, a value of 0.03 mg/kg was reported in India (171). It was concluded that dieldrin storage does not vary significantly according to age, race, and sex. This contrasts with the significant differences calculated for concentrations of DDT and DDE associated with these demographic variables in the same fat samples.

Individuals ingesting persistent pesticides establish storage concentration proportional to the amount ingested. The time required to establish equilibirum storage of DDE is unknown. Pesticide concentrations in excess of storage levels are excreted in the urine. Amounts in fresh water fish and marine shellfish are below storage levels. Continued monitoring is essential to maintaining low level concentrations in the aquatic environment and resources derived therefrom. Low level exposure of healthy adults to certain pesticides over periods of two years (169) did not show obvious hazard. Such studies must be extended to provide a sound epidemiological basis for defining safe chronic exposure limits.

THE PERSISTENCE AND DEGRADATION OF PESTICIDES IN THE AQUATIC ENVIRONMENT

Most of the surface waters of the United States contain chlorinated hydrocarbon insecticides and certain herbicides (171). Pesticide residues and their degradation products are of particular concern because of their potential toxicity to many aquatic organisms and the adverse effects they might have on man through his drinking water and food. Current pesticide practices must be assessed and adjusted to adequately protect the aquatic system. A large number of variables are associated with the fate of pesticide residues. Many are only poorly defined and others have yet to be identified and evaluated.

The term "degradation" is used in a broad sense and will refer to any measurable chemical change in a pesticide under natural environmental conditions. Degradation may be "complete degradation" to inorganic end-products or "partial degradation" to intermediate organic products (172).

Degradation Mechanisms, Rates and Products

The degradation rates of pesticides and their by-products under natural conditions are of primary consideration in examining the effects on the aquatic environment. A compilation of 58 potentially waterborne pesticides, their degradation rates and products is presented in Table 2. The majority of these were obtained under laboratory conditions under a wide variety of procedures and test conditions. These results, although valuable are not readily related to each other or extrapolated to field conditions. Only a limited number of field studies have been reported. For example, discrete differences in time of persistence may occur for a single compound because it may be degraded via several physical, biological, or chemical pathways or a combination of these. The pathway depends on such environmental parameters as temperature, oxygen concentration and the presence of other reactive substances. To facilitate evaluation of existing knowledge the pesticides will be considered as chemically related groups.

Physical Influences on Degradation

The degradation of pesticides in the aqueous environment which is unique for each individual system is influenced by such physical factors as adsorption onto organic or inorganic particulate surfaces, transport between the aqueous and benthic phases along a waterway, or volatilization into the atmosphere. The result is a concomitant adjustment in the concentration of residue at the original site. Quantitative information on these processes has been obtained only recently and is still meager.

The interrelationship of the physical processes and degradation mechanisms and their rates is still largely undefined.

INSECTICIDES

Table 2 (Pages 58-68)

CHEMICAL CLASSIFICATION	USAGE	DEGRADATION (SPECIFIC CONDITIONS) AND METABOLITES	ACCUMULATION AND/OR LONGEVITY
I. CHLORINATED HYDROCARBONS A. Aldrin	Used as soil insecticide for control of ants, cutworms, grubs, beetles and cotton pests	a) Photoisomerization to photoaldrin - can be converted to more toxic lipophilic ketones. Photoisomerization produced by sunlight or microorganisms c) Aldrin $\xrightarrow[\text{Epoxidation}]{\text{River Water - pH 7.3}}$ Dieldrin - Same in distilled H_2O d) Aerobic and anaerobic degradation of Aldrin - rate under anaerobic sludge conditions slightly greater than aerobic - neither temperature (between 20° to 30°C) nor biological activity significantly altered rate (pH 7.3) e) Photodecomposition via sunlight (Photoaldrin 11 times more toxic than Aldrin) 188	a) Persisting residues may be magnified by concentration of lipophilic metabolites in food chains 187 b) Floc-forming bacteria can remove ~ 100 percent Aldrin from solution in 20 minutes in river water 178 c) Conversion 80 percent complete after 8 weeks; complete conversion possible 181 d) Anaerobic half-life approximately 1 week in biologically active wastewater sludge 172
B. Dieldrin	Control insects which infest vegetable and fruit crops - general soil inhabiting pests primary use is for termite control	a) No chemical conversion in river water - pH 7.3 - or in distilled water b) Photoisomerized (in water via sunlight - may be microorganisms) to Photodieldrin, which can be further converted to more toxic lipophilic ketones (Photodieldrin 11 times more toxic to vert. than Dieldrin) c) Under dilute aerobic sludge and anaerobic sludge, at pH 7 to 8, temperature 20°C and 35°C - no degradation	a) For 8 weeks, no conversion 181 b) Very persistent, residues may be magnified by concentration of lipophilic metabolites in food chains 187, 188 c) Very persistent under aerobic-anaerobic and microbial activity 172 d) Sediment sorption, initial sorption (0 to 26 percent) rapid within pH range 3 to 9.0, decrease with time. After 7 days, pH > 8, sorbed Dieldrin = 0, pH decreased - Uptake of Dieldrin by sediment time-dependent, salinity independent 184
C. DDT	Broad spectrum - cotton, soybean and peanut pests; also, timber, industrial and mosquitoes	a) Bacterial degradation of dichlorodiphenylmethane, a DDT metabolic product - Hydrogenomonas + DDT $\xrightarrow[\text{p-chlorophenylacetate}]{\text{Cometabolized}}$ DCM 195 b) DDT $\xrightarrow{\text{lake water}}$ TDE, principal product (also known as DDD) DDT $\xrightarrow{\text{porphyrins}}$ DDD, an intermediate of DDT c) DDT, DDD, DDE underwent no change in river water, pH 7.3 - no change in distilled water d) DDT $\xrightarrow[\text{lake water}]{\text{microbial isolates}}$ TDE → DDNS (both highly acridal) DDE also detected. Greater DDNS percentage in eutrophic water 197 f) Under anaerobic conditions: DDT $\xrightarrow{\text{A. aerogenes pH 7}}$ DDD → DDE (70%) ↕ Dechlorination due to reduced (FeII) cytochrome oxidase - DDT conversion requires O_2 in higher animals, but not microorganisms g) DDT $\xrightarrow[\text{rate dependent on available food supply}]{\text{trout intestinal microflora}}$ DDD → DDE DDT → DDD → DDE 20% conversion after 7 days	b) DDT - very persistent, minimally 7 years 196 c) No change after 8 weeks 181 e) Detroit River W/1 percent sedimented oils contained DDT concentration near 1 ppm 198 f) Cytochrome oxidase-Fe complex dissociated by light and O_2; this complex is believed responsible for dechlorination of DDT, ∴ may explain persistence of DDT in sediments 199 g) No metabolic breakdown of DDD after 10 days 200

Table 2 (Continued)

INSECTICIDES (Continued)

CHEMICAL CLASSIFICATION	USAGE	DEGRADATION (SPECIFIC CONDITIONS) AND METABOLITES	ACCUMULATION AND/OR LONGEVITY
		h) Anaerobic conditions: at pH 7 DDA $\xrightarrow{A.\ aerogenes}$ DPM → DBH → DBP - most highly degraded product reported i) DDT $\xrightarrow[pH\ 7]{A.\ aerogenes}$ DDD → DDMU → DDMS → DDNU → DDA → DBP or DDT → DDE Aerobic conditions produced considerably less conversion than anaerobic j) In waste water sludge, Anaerobic conditions: DDT $\xrightarrow[1\ to\ 2\ days]{x\text{-reducing cofactor}}$ DDD - microbial activity produced rapid conversion Aerobic conditions: No DDT conversion at 20°C - but some degradation at 35°C	h) Anaerobic conditions had little effect on dissimilation 201 i) Metabolic fate of DDT believed dependent on exogenous energy source - Conversions DDT → DDD in mineral media with tyrosine complete in 100 hours and apparently direct linear function of temperature 202 j) Under biologically active, anaerobic conditions, DDD had half-life < 1 week 173 k) Rate of DDT → DDD conversion inversely related to O_2 concentrations 203 l) Decay time of DDT is seven years in man, birds, insects and fish 204
D. Endrin	Major domestic use as a cotton insecticide	a) No conversion in river water, pH 7.3, or in distilled H_2O b) Anaerobic conditions in wastewater sludge: Endrin → 2 unidentified, extractable degradation products	a) After 8 weeks, no change 181 b) Ranking in order of increasing persistence under anaerobic conditions: Lindane, Heptachlor, Endrin, DDT, DDD, Aldrin, Heptachlor epoxide and Dieldrin 172 c) Uptake of Endrin by bottom sediment: at pH range of 3 to 10.5, rapid initial uptake, decrease sharply with time → after 7 days contact, pH > 7, Endrin sorption = 0 184 At salinity 13 to 17 0/00, rapid initial uptake, after 7 days contact, Endrin = 0. Above salinity 17 0/00, no Endrin sorption onto sediment
E. Chlordane	Control cotton pests, grasshoppers, termites and as a soil sterilant	a) Of major components of technical chlordane, only α- and γ-chlorane stable completely for 8 weeks in river water, pH 7.3 b) Photoisomerize in sunlight 205	a) 15 percent degradation in 8 weeks of other components 181
F. Endosulfan	Agricultural application for control of vegetable pests, cotton pests and as a soil sterilant	a) Contains two active isomers: Endosulfan I and II. Both isomers 70 percent reduced within one week in river water at pH 7.3. - Endosulfan alcohol believed decomposition product - Same results in distilled H_2O	a) Complete isomer decomposition within 8 weeks 181
G. Isodrin	For agricultural and forest pests. Similar use as Dieldrin and Endrin.	a) Photoisomerization to photoisodrin	a) "Rapid" detoxification 187
H. Heptachlor	Primarily a soil insecticide - primarily for corn, secondarily for commercial pest control	a) Photoisomerized $\xrightarrow{sunlight}$ Photoheptachlor b) Heptachlor $\xrightarrow[pH\ 7.3]{river\ water}$ 1-Hydroxychlordene - Same reaction observed in distilled water, however, by second week Heptachlor epoxide produced c) Heptachlor rapid degraded in anaerobic and aerobic waste water sludge d) Removal of Heptachlor from distilled water was 99.4 percent in 4 days 206	a) Persisting lipophilic residues food chain 187 b) Complete conversion within 2 weeks 181 At end of 4 weeks, equilibrium exists → (60 percent) 1-Hydroxychlordene and Heptachlor epoxide (40 percent) Heptachlor epoxide remained stable for 8 weeks c) Anaerobic degradation products more persistent than initial Heptachlor. Product persisted in biologically anaerobic conditions 42 days, but completely degraded after 266 days 172 d) Losses from volatilization included - can be a quite significant amount 203

INSECTICIDES (Continued)

Table 2 (Continued)

CHEMICAL CLASSIFICATION	USAGE	DEGRADATION (SPECIFIC CONDITIONS) AND METABOLITES	ACCUMULATION AND/OR LONGEVITY
		Heptachlor $\xrightarrow{\text{Degraded}}$ 1-Hydroxychlordene + Unidentified Product e) Heptachlor $\xrightarrow[\text{Metabol.}]{H_2O}$ 1-Hydroxychlordene $\xrightarrow[\text{Metabol.}]{H_2O}$ 1-Keto-Chlordene Photoheptachlor-Ketone $\xleftarrow[\text{Photoisomerization}]{h\nu}$ 205	
I. Telodrin	Agricultural	In river water, pH 7.3, 75 percent alteration in one week and 90 percent after two weeks - Same results in distilled water	At end of 4 weeks completely decomposed rather than chemically converted to a compound 181
J. Toxaphene	For control of grasshoppers, soil pests and pests which attack forage crops, cotton, soybeans and livestock ectoparasites		a) In a lake environment, toxaphene vertically transported 5 to 15 cm in sediment - sorption irreversible. Decreased from maximum concentration by factor of 2 every 4 months 177 b) Contrary to Veith and Lee (1971), desorption of toxaphene from sediments produces yearly fluctuations of μg/ℓ in toxaphene concentration in the water. Aquatic plants significantly concentrate toxaphene in large amounts 207
K. γ-Benzene Hexachloride also, Lindane	Wide use for control of cotton insects and rice stem borer. Also use on wood infesting pests.	a) In river water, pH 7.3, no BHC degradation b) Anaerobic degradation in thick sludge at 35°C. Lower Lindane concentration 95 percent in 2 days. - Rate depends on Lindane and sludge concentration - Anaerobic degradation temperature sensitive, at 35°C, rate of 0.3 μg/day/mℓ. At 20°C, very little degradation. Under aerobic conditions with dilute sludge at 20°C, daily small doses of Lindane for 57 days, had < 8 percent degradation after 117 days. Unidentified product produced which persisted for 42 days but completely removed within 266 days in thick 35°C anaerobic sludge. c) At pH 11.5 in aqueous solution, 98.5 percent Lindane removed in 6.5 hours. The first degradation product present only few hours, replaced by second decomposition product which eventually disappeared. 206 Lindane, little, if any, degraded by microbial activity in an aerobic environment. 1, 2, 4-trichlorobene, reported in Okey and Bogan and Metcalf, as an alkaline dechlorination product of Lindane, was also resistant to metabolic (microbial) attack. f) Under anaerobic conditions, volatilization of degradation products, produced in aqueous environment, accounted for loss of 83.2 percent of γ-BHC. Half-life calculated at 16 days. Biological mechanisms responsible for isomerization 16.1 percent degradation at end of 2,100 hours. Under aerobic conditions, identifiable degradation products were: The α-isomer of γ-BHC and ε-BHC In anaerobic conditions: α-BHC and δ-BHC but no ε-BHC. 203 g) In sea water, the α, β and γ isomers decay at different rates, α being the slowest (35 percent in 31 days). Chemical degradation rather than biological.	a) No degradation after 8 weeks 181 b) Half-life in anaerobic microbially active sludge was 1 day; half-life in anaerobic non-microbially active sludge was ∼ 170 days 172 d) Lindane adsorption onto lake sediments affected by sediment suspension concentration, organic matter content, Lindane concentration, clay content and Lindane to sediment ratio. 203 d) Half-life of ∼ 10 hours when tested in aquaria with fish 208 Stored samples of reaction mixture showed considerable γ-BHC concentration after 12 months at 20°C 209
L. Mirex	Fire ant control	No degradation biologically (fish). Chemically (in ponds) after 284 days.	High residuality, after 56 days very little decrease in residues in mud, water and vegetation 210 Residues up to 200 ppm found in goldfish 308 days after exposure to 1 ppm for 1 day

INSECTICIDES (Concluded)

Table 2 (Continued)

CHEMICAL CLASSIFICATION	USAGE	DEGRADATION (SPECIFIC CONDITIONS)		ACCUMULATION AND/OR LONGEVITY	
		f) 91 percent degraded after 4 weeks in distilled H_2O, pH 6.0	211	e) Uptake from solution by carp is a function of time - up to 5 mg/ℓ Half-life of metabolic residues calculated at 12 hours	213
		g) Main hydrolysis product, Diethyl fumarate (more toxic to minnows than parent) and dimethyl phophorodithioic acid in basic solutions - In acid solutions, degradation products are dimethyl phophorothionic acid and 2-mercaptodiethyl succinate. However, below pH 7, hydrolysis will not proceed for prolonged periods. Other hydrolysis products: Diethyl maleate and maleic acid - Pronounced toxic synergism between malathion and diethyl fummarate	191		
F. Ethion	Primarily used in agriculture	a) River water, pH 7.3, 50 percent decrease in concentration in 8 weeks - In distilled water, no change	181		
		b) Approximately 95 percent degraded after 6 weeks in distilled H_2O, pH 6	211		
G. Trithion	Primarily used in agriculture	a) In river water, pH 7.3, 90 percent reduction after 2 weeks - Decomposition products not identified	181	Complete disappearance in four weeks	
H. Fenthion	Mosquito larvicide. Also, agricultural use	a) 90 percent degradation after 2 weeks in river water, pH 7.3 Believed Fenthion → 4-Methylthio-m-cresol Believed Fenthion → Dimethyl-o-thio-phosphoric acid - No change in distilled H_2O	181	Complete degradation by fourth week	
		Residual life up to 4 days in lakes and ponds, not greatly influenced by pH (Mulla, 1963)	214		
I. Dimethoate	Agricultural	a) 15 percent degradation in 2 weeks in river water, pH 7.3	181	50 percent degradation after 8 weeks	
J. Azodrin	Agricultural	a) After 8 weeks in river water, pH 7.3, no change	181		
K. Fenitrothion (MeP)	Agricultural	a) 73.8 percent degraded in 3 weeks in pH 6.0 distilled H_2O	211		
L. Phosdrin	Agricultural	a) At pH 6 in distilled water rapid hydrolysis. After 4 weeks approximately 98 percent degraded. However, according to Porter-1964, the half-life in slightly acidic solutions was 3 months.	211		
M. Ronnel	Agricultural	a) Approximately 95 percent degraded after 1 week, in pH 6.0 distilled H_2O	211		
N. Dursban	Agricultural	a) Conversion to phosphate analog by rainbow trout but such conversion does not occur in goldfish			
III. CABAMATES					
A. Sevin	Broad spectrum application	a) In river water, pH 7.3, 95 percent reduction in one week	181	Complete degradation by second week	
		1-Naphthol, suspected degradation product was not detected after parent decomposition, perhaps rapid decomposition			
		b) Sevin and 1-Naphthol metabolite completely degraded in lake water after 3 days, pH 8.5	179		
B. Zectran		a) 85 percent degradation after one week in river water at pH 7.3	181	Complete degradation by second week	
		Suspected degradation product, 4-Dimethyl-amino-3, 5-Dimethyl Phenol, was not detected			
C. Matacil		a) 90 percent degradation by second week in river water, pH 7.3 - No suspected decomposition products detected	181	Complete degradation by fourth week	
D. Mesurol		a) 100 percent degradation within one week in river water, pH 7.3 Decomposed to → Methyl carbamic acid Decomposed to → 4-Methylthio-3, 5-Dimethyl Phenol	181	The phenol degraded slowly, by fourth week it was not detectable	
E. Baygon		a) After one week in river water, pH 7.3, 50 percent hydrolyzed to its phenol; after 2 weeks, 70 percent; 4 weeks, 90 percent; and 8 weeks, 95 percent degraded - The phenol was also degraded such that it was not detected after 8 weeks.	181		

INSECTICIDES (Continued)

Table 2 (Continued)

CHEMICAL CLASSIFICATION	USAGE	DEGRADATION (SPECIFIC CONDITIONS) AND METABOLITES	ACCUMULATION AND/OR LONGEVITY
II. ORGANOPHOSPHATES			
A. Parathion	Used as larvicide for mosquito control ∴ direct spray entry into water Also, to control peach pests and other fruit and vegetable pests	The general rule for hydrolysis in distilled H_2O is the increase in rate with decrease in sulfur content of the organophospate ester. 211 a) In river water, pH 7.3, Parathion and Methyl parathion Hydrolyzed → p-Nitrophenol → Diethyl and Dimethyl-o-thio-phosphoric acid In distilled H_2O, no change in compound, suggesting a biological degradation b) In sterilized sediment systems, adsorbed and in solution Parathion $\xrightarrow{\text{Hydrolyzed}}$ Diethylthiophosphoric acid → p-Nitrophenol - In natural sediment, only parathion is solution was hydrolyzed. Rate of hydrolysis 0.15 to 0.18 percent/day. Catalyzed at pH > 7. In anaerobic, microbial environment: Parathion → Aminoparathion, stable for 150 days In aerobic, microbial environment: Parathion → Aminoparathion + x-compound (w/Benzenoid and Phosphoric Acid moieties) d) At pH 6.6 to 7.3, Parathion present in water (0.01 ppb), 4 months after last application e) After 6 weeks in aqueous solution, 82.2 percent degraded (ph 6.0) f) W/B subtilis - under aerotic conditions - Unable to oxidized methyl parathion but formed aminomethylparathion, dimethylthiophosphoric acid and aminodesmethyl parathion. The amino-form was the main product. - W/B subtilis - anaerobically, only amino-form produced. 180	a) Less than 5 percent Parathion compound remained after fourth week 181 10 percent Methyl parathion remained by 2 weeks, 0 percent by fourth week b) In sediment (from lake with pH 4.7), solutions 26 percent degraded in 92 days 180 In sediment (from lake with pH 7.2), solutions 28 to 39 percent degraded in 54 days ∴ w/o microbial activity, Parathion would persist for months, while in biologically active (anaerobic or aerobic) environments, persist only few weeks c) 50 percent hydrolyzed in water in 120 days 212 d) Parathion stable indefinitely in neutral and acid solutions at room temperature at pH > 9, and temperature increase - considerable hydrolysis e) Most persistent of the organo phosphates 211 g) Methyl parathion and Parathion were much more persistent in lake water than soil water. Residues in lake water up to nine months, whereas only 1 month in soil water. 179
B. Ciodrin	Agricultural	a) Hydrolysis is acid-catalyzed, resistant to chemical hydrolysis 180	
C. Diazon	Effective against many fruit and vegetable pests	a) Hydrolysis is acid or base catalyzed, forms 2-isopropyl-4-methyl-6-hydroxypyrimidine, which is microbially degradable - Resistant to chemical hydrolysis 180 b) 95 percent degraded after 5 weeks, is distilled H_2O, pH 6.0 211	
D. Sumithion	Agricultural	a) W/Bacillus subtilis - aerobic degradation 180	
E. Malathion	Used to control certain pests of fruits, vegetables and ornamentals. Also used for public mosquito control.	a) Malathion can be, under aerobic conditions, microbially degraded - 99 percent in 24 hours 182 With aeration alone, 55 percent hydrolyzed in 24 hours b) Easily hydrolyzed in water above pH 7.0 c) Completely degraded in river water, pH 7.3, within four weeks - Metabolites not identified - Same test run in distilled water, no hydrolysis 181	d) (Weiss and Gakstatter - 1965) Persistence dependent on pH. Half-life in solution of pH 6, 7, and 8 ranged from 3 months to 1 week, respectively. 213

Table 2 (Continued)

HERBICIDES (Continued)

CHEMICAL CLASSIFICATION	USAGE	DEGRADATION (SPECIFIC CONDITIONS) AND PRODUCTS		ACCUMULATION AND/OR LONGEVITY
IV. HETEROCYCLIC NITROGEN DERIVATIVE HERBICIDES				
A. S-Triazines	Weed control among vegetable crops	Low water solubility		
1) Simazine	Used to control weeds in maize. Also, effectively used to control aquatic weeds in ponds, lakes, and fish hatcheries.	1) Slight degradation evidenced after 21 days	226	1) Sunfish absorb amounts directly proportional to solution concentration - Residue located in Viscera - Released after 7 days in clean H_2O No storage
V. ALIPHATIC ORGANIC NITROGEN HERBICIDES				
A. Substituted Ureas				
1) Monuron	Agricultural herbicides and soil sterilants	1) In river water, pH 7.3 (lab conditions), complete degradation in 8 weeks. Suspected this compound would hydrolyze to its amine and Dimethyl carbamic acid.	181	
		2) One identified photolysis, aqueous product is 3-(4-Chloro-2-hydroxyphenyl)-1,1-dimethylurea (Tang and Crosby, 1968).	216	
2) Fenuron	Agricultural herbicide	1) In river water, pH 7.3 (lab conditions), complete degradation in 8 weeks. Suspected hyrolysis to its amine and dimethyl carbamic acid.	181	
3) Diuron	Soil sterilant action	1) Partial detoxification by bacterial organisms	193	
4) Linuron	Agricultural herbicide	After 2 months of sunlight, aqueous exposure, 13% 3-(3-Chloro-4-hydroxyphenyl)-1-mehtoxy-1-methylurea, 10% 3,4-Dichloro-phenylurea and 2% 3-(3,4-Dichlorophenyl)-1-methylurea (Rosen, et al, 1969)	216	
5) Metabromuron	Agricultural herbicide	Irradiation in aqueous solution for 17 days yielded - 80% original parent composition+15% 3-(p-hydroxyphenyl)-1-Methoxy-1-Methylurea+3-(p-bromophenyl)-1-methylurea+p-bromophenylurea+unidentified products (Rosen and Strusz, 1968)	216	
B. Carbamates	Agriculture - most effective in preemergence application	Refer to insecticide chart for individual compounds		
IV. MISCELLANEOUS				
1. Merphos (organophosphate)	Defoliant	In river water, ph 7.3, lab conditions, merphos converted within 1 hour via oxidation to DEF - 100% conversion. However, after 1 week, only 50% of DEF was recovered; after 8 weeks, less than 5% was recovered. $P(C_4H_9S)_3 \xrightarrow{[O]} PO(C_4H_9S)_3$	181	
2. Pichloram	Brush killer and aquatic herbicide	1) Photodecomposition in aqueous solution yields nonphytotoxic products	223	
		2) Products of phtolysis in water not isolated by suspected hydroxyl replacement of chloride (Redemann, et al, 1968)	216	3) More persistent than 2,4-D or 2,4,5-T residues of 6 ppb lasted up to 180 days after spray into shallow pond
3. Dursban	Very similar to pichloram	1) In aqueous solution, ph 8.0, 3,5,6-Trichloro-pyridinol rapidly degraded - All chlorines liberated - 14 products detected (Smith, 1968)	216	
4. Diquat	Aquatic herbicides	1) At 3 ppm application, negligible residues were detected after 21 days - A significant portion being lost after 3 days. - Loss may be degradation or adsorption - The majority of the 16 chemicals listed: Dichcone, Molinate, Propanil, Na-Arsenite, Diquat, Dichlobenil, Paraquat, Amitrole, Amitrole T, Endothall, Diuron, Silvex, Fenac, Monuron, MCPA and 2,4-D have been found to readily decompose in aqueous, sunlight solutions (Crosby, et al, 1965)		

Table 2 (Continued)

FUNGICIDES

CHEMICAL CLASSIFICATION	USAGE	DEGRADATION (SPECIFIC CONDITIONS) AND PRODUCTS	ACCUMULATION AND/OR LONGEVITY
1. PCP	Fungicidal use, in addition to its herbicidal use	Discussed under herbicides	
2. Carboxin	First synthetic fungicide	Oxidation retarded at high pH. Main degradation pathway was carboxin $\xrightarrow[H_2O]{}$ Sulfoxide form. At pH 2 and 4, further oxidation of Sulfoxide to Sulfone 227	

HERBICIDES (Concluded)

Table 2 (Continued)

CHEMICAL CLASSIFICATION	USAGE	DEGRADATION (SPECIFIC CONDITIONS) AND PRODUCTS	ACCUMULATION AND/OR LONGEVITY
		3) Very water soluble - decomposes above pH 9→ colored products 223 - Strongly adsorbs onto clay. Photodegradable	2) Diquat, upon contact with sediments, is immediately and completely in activation. (Fundburk and Lawrence - 1964) Reported rapid adsorption and concentration of diquat by plants 40 to 60 times amount in water
5. Paraquat	Aquatic herbicide	1) More stable than diquat 223	1) Very strong adsorption onto clay

HERBICIDES (Continued)

Table 2 (Continued)

CHEMICAL CLASSIFICATION	USAGE	DEGRADATION (SPECIFIC CONDITIONS) AND PRODUCTS	ACCUMULATION AND/OR LONGEVITY
3) 2,4,5-T	Used most effectively on woody plant species and such crops as hay, rice, pasture and sugar cane	1) Predicted photodecomposition in aqueous solutions to Phenol products, similar to 2,4-D	2) Applied at rate of 4 lb/acre to watershed, 600 ppb in water after 2 days; 90 ppb after 21 days 219
4) Silvex	Effectively used against woody plants and soybeans	1) Photodecomposition to Phenol products 2) In water and water-sediment systems, PGBE ester produced. Rate of PGBE degradation dependent on initial concentration but completely degraded.	2) Silvex concentrations continually decreased for 5 months 229
B. Phthalic Acid Compounds			
1) Endothal Derivatives (Disodium Endothal and TD-47)	Control of aquatic vegetation in fishery habitats when water temperature > 60°F - Also used as preemergence herbicide to prevent weed germination	1) Decomposition of TD-47 lowered D.O. to sufficiently low concentration to kill fish (-4) 220 - Higher Ca-concentration tended to reduce toxicity - Increased temperature - increased toxicity - Degradation of TD-47 in aquaria is rapid in first week. Rate is direct function of time and concentration - Immediate absorption by plants after application. Endothal amines released	Effective control of weeds for 1 month - Endothal (amines) residues may concentrate in organic matter associated with bottom muds - Some residues found in fish food organisms 3 weeks after application - 10 ppm residues required 25 days to disappear
C. Benzoic Acid Compounds			
1) Amiben	Soil sterilant used on soybeans, tomato plants and other vegetable crops	1) (Sheets, 1963 and Crosby, 1966) - Report rapid photolysis by sunlight in aqueous solutions 216 - Phenolic degradation products detected. 2) Amiben and its Methyl ester photolyzed in daylight to dark color indicating hydrolysis and dechlorination. Products recovered were not identified. 222 3) (Isensee, 1969) - Biological activity diminishes during irradiation. N-Benzoyl derivative is more light stable. 216	
D. Phenylacetic Acid 1) Fenac	Used in agriculture, aquatic weed control and right-of-way weed control	1) Irradiation of Na-Salt by UV light yields mixture acidic and neutral compounds. Major identified product is 2,5-Dichlorobenzyl alcohol; Di- and Trichlorobenzaldehydes probable minor products themselves are photolabile (Crosby, 1966) 216 - Irradiation of one of the more simple constituents of Fenac, Monochlorophenylacetic acid ↓ Benzyl Alcohol + Benzaldehyde + O-Chlorobenzaldehyde	
III. ALIPHATIC ACID HERBICIDES			
1) PCP	As an insecticide, molluscicide, herbicide, fungicide and bactericide. Controls termites, wood insects, snails. Used as weed killer, cotton defoliant and wood preservative	1) Decomposes in sunlight - monomeric and dimeric oxidation products formed by photolysis of the Na-Salt in H_2O (Kuwahara, et al, 1966) 223 - Violet colored solution. Major products identified as: Chloranilic acid and 3,4,5-trichloro-6-(2'-hydroxy-3', 4', 5', 6'-tetrachlorophenoxy)-O-benzo Quinone. 216	
2) Bromoxynil	Treatment for broadleaf weeds	1) Decomposes in light, in aqueous solution, to polyphenols and colored polymeric materials.	
3) Dichlobenil	Preemergence herbicide effective against many submerged aquatic weeds - not filamentous algae - controls alfalfa weeds	1) Temperature strongly influences degradation rate. In 77 to 89°F pond, only 3% of compound left after 11 days; in 67 to 73°F pond, 3 weeks before maximum concentration in water - measurable after 189 days. Greater toxic action with time for invertebrates - suspected bottom accumulation 225	1) Dichlobenil present in bottom sediments of warmer pond after 312 days and after 166 days in colder pond (due to mode of application) 225 - Residues to fish reduced to negligible levels in 2 months 2) Residues found in water, hydrosoil and organisms. After 14 days, hydrosoil contained larger amounts than water; present in water and soil 64 days after treatment but not in organisms. The metabolite 2,6-Dichlorobenzoic acid never detected.

HERBICIDES

Table 2 (Continued)

CHEMICAL CLASSIFICATION	USAGE	DEGRADATION (SPECIFIC CONDITIONS) AND PRODUCTS	ACCUMULATION AND/OR LONGEVITY
I. INORGANIC			
1) Sodium Arsenite	To remove filamentous algae and rooted aquatic vegetation in fish farm ponds		Dupree (1960) - Removal from water phase by bottom mud -- but desorption back into water phase possible; absorption by phytoplankton up to 714 ppm
Organic Arsenicals	Used extensively in cotton farming as selective post-emergence herbicides		
2) Copper Sulfate	Algae control in water	Increase copper uptake when CSP applied with diquat. 215	Large percent of applied quantities adsorb onto bottom muds. Residue readily uptaken by plants.
II. CARBOXYLIC AROMATICS			
A. Phenoxy Herbicides			
1) 2,4-D (Ester form and Na-Salt)	Used to control aquatic vegetation in water systems; also broad-leafed cereal grain crops and military defoliant	1) 2,4-D (acid) photolyzed in aqueous solution under lab conditions to humic acid 216 2,4-D (acid) → 2,4-Dichlorophenol → 4-Chlorocatechol $\xrightarrow{UV}$ 1,2,4-Benzenetriol 2,4-D (acid) (to very small extent) → 2-Hydroxy-4-Chlorophenoxy-acetic Acid 1,2,4-Benzenetriol (light-independent) Rapidly Air Oxidized → Mixture of Polyquinoid humid acids (insoluble) Accompanying decrease in pH during degradation due to the production of 2 moles HCl/ 1 mole 2,4-D degraded 2) Esters of 2,4-D $\xrightarrow[\text{20 min}]{\text{UV - Distilled } H_2O}$ 2,4-Dichlorophenol - Accompanying pH decrease from 7 to 3+ - Rate of decomposition increasing with pH increase being much faster at pH 9 than pH 6 or 7 - Degradation of Phenol form much faster at pH 9 than 6 -- biological degradation of Phenol form - 2,4-D biologically decomposed in relatively short time in lake bottom mud 4) Strong 2.1 unit decrease in pH within two weeks of application. Normal pH after 1 month. Control of plants up to and over 1 year, depending on flow rate of water	2) Sorption of the sodium salt form of the three 2,4-D Ester forms onto Bentonite, Illite and Kaolinite is small and considered insignificant 218 2,4-D persisted up to 120 days in lake water aerobically incubated in lab. Phenol may persist much longer in low pH, O_2 conditions. Removal of 2,4-D from water by Ca- or Mg-precipitation unlikely 3) 2,4-D spray on watershed at 4 lb/acre showed 1,000 ppb in water 2 days after and only 40 ppb 21 days after spray. 219 4) DMA 2,4-D removal by water treatment plants, little, if any 186 - Dimethylamine salt of 2,4-D appears to be non-cumulative - Within 24 hours - 100% 2,4-D that was in water column was adsorbed onto Plankton and retained it for 6 months. 5) 1 hour after treatment - 37 ug/l detected in water column, less than 1 ug/l present after 8 hours. However, 0.14 mg/kg to 50.0 mg/kg present in mud samples - lasting up to 10 months after application. 185
2) 4-(2,4-DB)	Aquatic weed control	1) 4-(2,4-Dichlorophenoxybutyric) acid $\xrightarrow{\text{Bluegills (Fish)}}$ 2,4-D 217 Bluegills = *Lepomis gibbosus* - Linear increase in 2,4-D production with time - No toxicity as result of conversion 2) Based on 2,4-D as model for Phenoxy herbicides, 4-(2,4-DB) predicted to undergo photodecomposition to yield Phenols	

MISCELLANEOUS PESTICIDES

- Table 2 (Continued)

CHEMICAL CLASSIFICATION	USAGE	DEGRADATION (SPECIFIC CONDITIONS) AND METABOLITES	ACCUMULATION AND/OR LONGEVITY
1. Rotenone	Piscicide	Time dependent changes in Rotenone toxicity - Correlated to the transition from colloid to a dissolved state. - Toxic change proceeds at greater rate at high temperature - Inactivation 6 to 15 days in water solution - Unstable in light, temperature increase increases effectiveness 192	
2. Cabaryl	Used to control ghost shrimp in oyster beds Also used as insecticide against pests of fruit, nuts, vegetables, forage crops and cotton	a) In sea water, hydrolyzes to 1-Naphthol (Karinen, et al., 1967). 1-Napthol is quite unstable in alkaline sea water. 190 1-Naphthol $\xrightarrow{\text{Light and Microorganisms}}$ CO_2 + Unidentified Products (more toxic to clams and fish than parent compound) - Degradation in light and dark produced different degradation products - Precipitate forms upon exposure to light (red color) contains stable free radical (2/3 toxic as 1-Napthol) - In sterile, an-aerobic, light-exposed systems, 1-Napthol decreased 0.3 percent per day for 30 days - With O_2, degradation rate was 1.6 percent for 60 days; its degradation attributed to photooxidation rather than photodecomposition - Optimum stability of 1-Napthol is pH 6.3, but unstable at pH 8.2, the pH of sea water b) Degradation by the fresh water algae, *Scenedesmus*; suspected hydrolysis and oxidation to form N-Methyl carbamic acid + NH_3 + Formic Acid 193	Treatment of mud flats with Caberyl failed to recolonize with mussels for 18 months
3. Antimycin	Piscicide - used in marine habitats	c) Rapid breakdown above pH 8.5. Increase in toxicity as temperature increases - Degradation in fresh water directly related to hardness. Exposure to light and more alkaline waters, becomes sublethal in 2 to 10 days. Detoxification first to occur in surface waters. 194	Residuality in fresh water - 24 to 96 hours (Walker, et.al. - 1964) Residuality in salt water - 5 days

Adsorption:

Many pesticides are almost insoluble in water but can be found in significant quantities in the aqueous and sediment phases of water bodies because they have sorbed to various solids that act as condensation nuclei (173). Therefore, understanding the sorption phenomena prior to evaluation of degradation and transport processes is important. Sorption is not a degradation mechanism but it alters the availability of the pesticide for subsequent chemical or biological degradation .

The extent of pesticide sorption is related to the solubility of the compound, the nature of the sorbing material and other properties of the aqueous system. Strong sorption bonds to clay minerals are characteristic of some pesticides, such as DDT (174).

Chemical Reactions

Hydrolytic mechanisms are accelerated by sediment sorption. The rate of reaction is season and pH dependent, i.e., if the pH is held constant, the rate of degradation is related to time by first-order kinetics. Atrazine hydrolyzes to the non-toxic compound, hydroxyatrizine. The reaction has been shown to be catalyzed by sorption onto colloidal surfaces (175, 176). The catalysis is apparently associated with sorption at -COOH groups of the sediment. The literature is deficient in similar sediment-catalyzed degradation for other chlorinated hydrocarbons. The relationship of the sorption process to chemical degradation mechanisms of pesticides has not been specifically established.

Biological Degradation

Sorption onto sediment influences degradation by enabling pesticide compounds to settle to the bottom of water systems where they become subject to microbial activity (173, 177). Bacteria sorb pesticides during flocculation and settling processes. Gram-positive bacteria isolated from Lake Erie have sorbed 1 part per million (ppm) of aldrin from water in 20 minutes (178). Chlorinated hydrocarbon degradation, subsequent to settling of the pesticide particle complex to microbially active sediments, has been demonstrated (177, 179).

Organophosphate degradation in sediments is also catalyzed by the presence of microbiological organisms (180, 181, 182). Parathion, the most resistent of the organophosphates, is readily subject to biodegradation in microbially active lake sediments. Without microbial activity, parathion would remain in the natural environment for months, while in microbially active environments, it is degraded in a matter of weeks (180).

Cycling (Physical)

Sorption of pesticides followed by settling does not assure retention in the bottom sediments of aquatic systems. The pesticide may be cycled into overlying waters by spring and fall overturns in lakes and reservoirs, and from an increase in the scouring velocity of flowing streams (173). Changes in pesticide concentrations can result from release or desorption of the pesticide from the particle through stresses on dynamic equilibrium processes. Heptachlor, dieldrin and DDT sorb very quickly onto clays (174) but desorption may occur although the rate is usually lower than for sorption (183). Sorption-desorption rates in aqueous systems are particularly influenced by salinity, pH and organic materials. A study conducted with endrin and dieldrin demonstrated this effect (184). An analysis of the estuarine sediment showed 14 to 18 percent organic content, 31 percent sand, 25 percent silt, 16 percent clay, and the balance other organic material and compounds. Table 3 relates the effects of added organic material, pH and salinity to sorption of endrin and dieldrin. These processes of sorption, sedimentation and subsequent return to solution of pesticides suggests a mechanism by which aquatic organisms can be exposed to pesticide effects long after the initial release. Very little has been documented regarding the relationship between sorption-desorption and degradation mechanisms.

Translocation:

Reservoirs

Natural hydrological dynamics involve consideration of current, turbidity and temperature. These control the transport of pesticides in the aqueous media. The distribution of pesticides in the water influences the rate and mechanisms of chemical degradation and the availability of these substances for biological uptake. These factors can be observed in the case of direct application of a pesticide to a reservoirs' surface. Widescale applications of the herbicide, 2,4-dichloro-phenoxyacetic acid (2,4-D) have been made to reservoirs of southern Tennessee, northern Alabama and northern Georgia in 1967 and 1971 to control the aquatic plant, Eurasin Water Milfoil (185, 186). The pesticide was monitored in flowing and static zones.

Table 3

Factors Influencing Sorption of Endrin and Dieldrin (184)

Pesticide	Presence of Organic Materials	pH	Salinity
Endrin	High initial sorption however, after 7 days of contact, insignificant amount of endrin associated with sediment.	39-43% uptake within one day in pH range 3 to 10.5 (after 7 days at pH 7.0 most of initially sorbed endrin released from sediments).	Sorption maximum in range 13 to 17% after 1 hour. Complete desorption after 7 days. Salinity above 17% and pH 7 to 8 - no sorption occurred.
Dieldrin	Insignificant influence during 7 day period.	Initial uptake at pH 3.8 was 26%; at pH 8.0 initial uptake was 0% after approximately 70 hours of contact, maximum sorbed quantities ranged from 58-64%. At pH 8.0 complete desorption after 170 hours of contact.	Sorption independent of salinity.

Source: Rowe et al. (184)

In conclusion, sorption of both endrin and dieldrin is time-dependent and pH sensitive. Endrin sorption is salinity dependent but dieldrin sorption is not.

As a first treatment, 888 tons of the 20 percent ethanol ester form of 2,4-D were applied in granular form to 8,000 surface acres of seven reservoirs in eastern Tennessee and northern Alabama. These reservoirs are spread over a main-channel distance of 352 river miles. Application varied from 60 to 100 lbs. of 2,4-D acid equivalent per acre. Seven monitoring stations were located on the Guntersville Reservoir in Alabama. Five stations were located on Watts Bar Reservoir in Tennessee. Twenty-four hours after application, water milfoil samples contained concentrations up to 8.26 milligram per kilogram (mg/kg) indicating active uptake of the herbicide. Sediment samples, taken from static water areas (embayments), contained higher and more persistent residue concentrations than did areas of rapid current. In Watts Bar Reservoir, significant concentrations of 2,4-D were found in mud samples as high as 58.8 mg/kg dry weight after 10 months. Municipally treated water samples contained less than 1 ug/l of the herbicide.

In the 1971 study, surface areas in the Nickajack and Guntersville reservoirs in Tennessee and Alabama, respectively were treated with approximately 170,000 gallons of the dimethylamine salt (DMA) of 2,4-D in April. Posttreatment monitoring continued for four months. Application amounts were 20-40 lb./acre of active ingredient. The liquid form proved to be more suitable than the granular form because of its direct toxic action to the root crowns of the water milfoil and dispersal to marginal areas of the beds. One monitoring station was located so that it was restricted to static water. At this site, vertical stratification of 2,4-D occurred between the time of application and the eight-hour sampling period in Guntersville Reservoir. A concentration of 5 mg/l was present at the surface while only 1.5 mg/l occurred at the level of milfoil root crowns following a 40 lb./acre application of active ingredient. Within two weeks, the 2,4-D content in this embayed area was uniform at 0.65 mg/l. One month later it was 1.0 ug/l. This treatment level prevented regrowth for approximately 12 months. A pH decrease of 2.1 units, from 8.5 to 6.4, occurred between the first and the fourteenth day after treatment. The pH returned to the pretreatment value a month later. Another monitoring station was established adjacent to the main channel of the Tennessee River where conditions were favorable for rapid dilution of the herbicide. Less than 0.87 mg/l was present in the water within 24 hours after treatment with 40 lb/acre. Less than 5.0 ug/l was measured 14 days later. Lower application rates of DMA 2,4-D, as opposed to the granular form, led to variable residence times in the water. Concentration level and residence time were closely related to water flow rates and effectiveness of plant control. Liquid DMA 2,4-D was readily sorbed by planktonic organisms. The plankton removed 24 percent of the herbicide within one hour after application and a proportional amount during the next 7 hours. A trend of progressive downstream dilution of waterborne 2,4-D was observed over 214 miles. This was indicated by the concentrations of 2,4-D that accumulated in mussels located on the bank edges of tributaries and channel slopes. One anomalous pretreatment sample of mussels below Guntersville dam contained the highest 2,4-D concentration found at any time during the monitoring. The source of 2,4-D was unknown. Water from the treated areas continued to be used for domestic purposes during this period without user complaints. Finished drinking water contained 1 to 2 ppb concentrations of 2,4-D after standard treatment practices.

Hydrological influences on the distribution of other chlorinated hydrocarbons and organophosphates under natural flowing and static freshwater systems have not been reported for all the United States.

A number of conclusions can be formulated regarding the transport and distribution of pesticides in reservoirs:

- Pesticides are more persistent in static water areas (both aqueous and sedimental levels considered) than in those subjected to dynamic current action.
- Pesticide concentrations in the aqueous-phase are further influenced by: (a) presence of thermal stratification and (b) the amount of plankton present.
- The physical form in which the pesticide is applied (aqueous vs. granular) influences the degree of desired effectiveness upon application to water.
- Pesticides such as 2,4-D are not completely removed from raw water during conventional treatment practices.

Toxicity

Laboratory studies have shown that photoisomers of aldrin, dieldrin, and heptachlor are more toxic than the parent compounds to such freshwater organisms as fish, amphibia, flatworms and crustacea. Sunlight catalyzes the production of such photoisomers (187, 188). Photoaldrin is 11 times more toxic to mosquito larvae than aldrin (179). Photoisodrin, however, was shown to be less toxic than either isodrin or endrin.

The seawater hydrolysis product, 1-naphthol, of carbaryl (sevin) has been shown to be twice as toxic to fish as the parent compound when both were tested at 1.3 mg/l. It is also more toxic to young clams at a concentration of 6.4 mg/l than carbaryl (190). A reddish precipitate results from the instability of 1-naphthol under alkaline conditions. The precipitate was found to be two-thirds as toxic as 1-naphthol to bay mussels (190).

With the fathead minnow, the basic hydrolysis product, diethyl fumarate, was more toxic than malathion (191). A pronounced synergistic effect between malathion and its basic hydrolysis products was shown. This occurred when 64 percent of the TLm concentration of malathion had hydrolyzed to form diethyl fumarate. Therefore, the difference of a day or two in the application time of malathion on two adjacent areas could result in a condition in which a considerable quantity of the breakdown product, along with a substantial quantity of the parent compound, could be washed into a common water source.

ALTERNATIVES TO PESTICIDES IN THE UNITED STATES

Pest management should encompass the totality of knowledge of all pest control methods. Selected control measures should be those which consider the long term ecological and economic aspects. The introduction of pesticides to agricultural practice has been beneficial. Problems have arisen, some quite serious, which detract from the benefits (229,230) and these may be attributed in a large measure to a disregard of ecological considerations.

The initial benefits of pesticides were so evident that alternatives were not evaluated with equal vigor. All practices, whether chemical, cultural, physical, genetic or biological, must bring about the most effective, least ecologically disruptive, pest control possible. The objective is to reduce the harmful impact of pesticides upon the aquatic environment by critically analyzaing the available alternatives.

Methods of control are effective because they either directly affect the pest species or adversely modify environmental conditions necessary for its survival (Fig. 1). The Administration has reviewed pesticide usage to include agriculture, industry, manufacturing and home use and initiated integrated control systems.

Cultural Methods of Pest Control

Cultural methods are routinely utilized in agriculture to reduce pest problems by adjusting the time or manner of performing operations for the production of crops or animals, and in improved management procedures. Examples of such cultural methods (232-236) and the pest species against which it is directed are:

Sanitation:

Destruction of crop refuse (boll weevil, bollworm, corn borer)

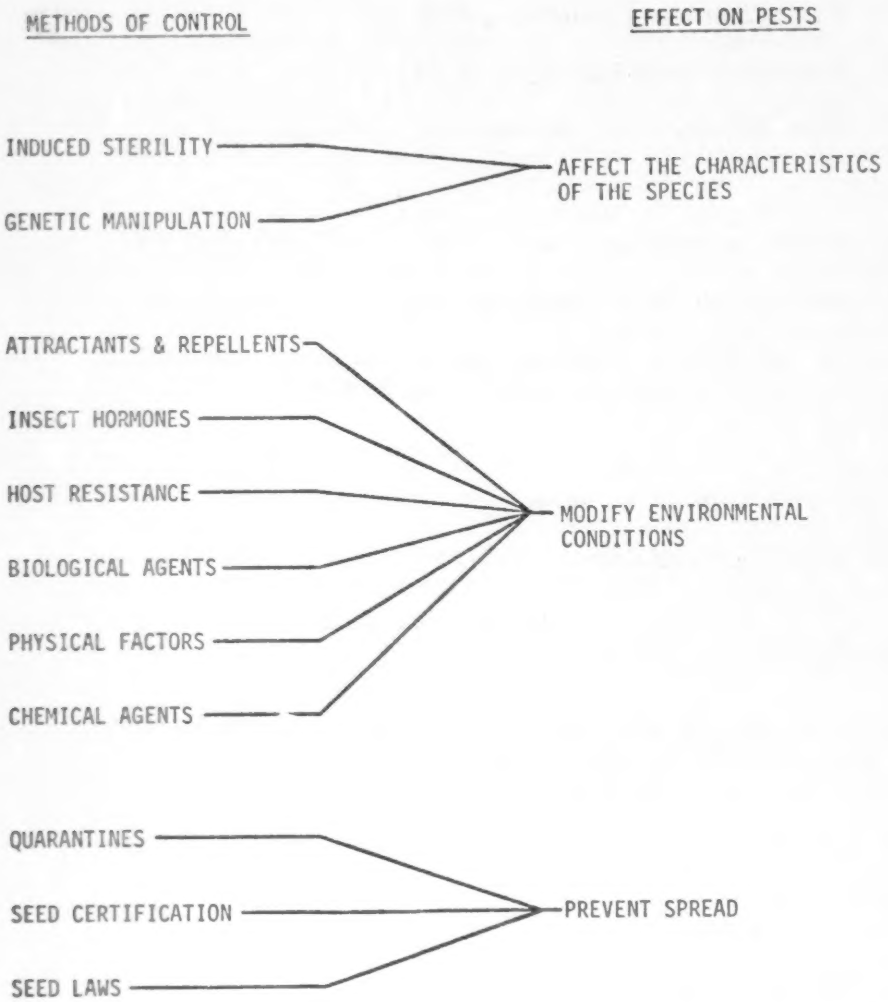
Cleaning of field borders (weed control)

Disposal of wastes (fly control)

Rotations:

Crop rotation (specific pests for all crops, diseases, fungal spores, bacteria, mites, insects and viruses, e.g., golden nematodes of potatoes, soybean cyst nematodes, northern corn rootworm)

Animal rotation (cattle tick control)


METHODS OF CONTROL
EFFECT ON PESTS
INDUCED STERILITY
GENETIC MANIPULATION
AFFECT THE CHARACTERISTICS OF THE SPECIES
ATTRACTANTS & REPELLENTS
INSECT HORMONES
HOST RESISTANCE
BIOLOGICAL AGENTS
PHYSICAL FACTORS
CHEMICAL AGENTS
MODIFY ENVIRONMENTAL CONDITIONS
QUARANTINES
SEED CERTIFICATION
SEED LAWS
PREVENT SPREAD

Source: Rabb and Guthrie (Modified) (247)

FIGURE 1 POSSIBLE METHODS OF PEST CONTROL

Farm Management:

- Land bank and fallowing (cyst nematodes)
- Strip cropping (alfalfa aphid)
- Fertilizers (chinch bugs, weeds)
- Time of planting (southeastern corn borer, sugar-beet nematode)
- Pest free seeds and seed certification (weed control, wheat nematode control)
- Destruction of volunteer plants (potato aphids)
- Destruction of alternate hosts (wheat and apple rusts, beet leaf hoppers, sweet potato weevils)
- Destruction of early blooms (sorghum midge)
- Tillage (grape berry moths)
- Crop spacing (weeds)
- Cleaning of farm equipment (weed control)

Trap crops (citrus red mite and corn ear worm)

Regulation of plant stands (cover crops for beneficial insects for biological control of citrus pests)

Selection of site (various forest insects)

Thinning, Topping, Pruning and Defoliating (Tobacco hornworm, mite, and control of dutch elm disease)

Water Management:

- Irrigation and flooding (root knot and white tip nematodes)
- Impoundment and improved pond management (aquatic weeds, mosquitoes, biting midges)
- Drainage (nematodes)

Cultural Control of the Southwestern Corn Borer

This corn borer is a pest in the western United States and western Tennessee and Alabama (237). Burying is not detrimental to the larvae but the moths are unable to emerge from the soil. Early planted corn escapes some of the damage. The primary advantage for early planting is reduction in girdling.

The use of an early maturing hybrid is not an acceptable substitute for early planting as a means of reducing damage caused by this borer (237).

Cultural Control of Cotton Pests:

Insect Control

The pink bollworm is controlled by cultural practices which include stalk destruction and deep plowing of the residue after the crop is harvested. Overwintering as larvae and a single host plant (cotton), makes it highly susceptible to this method of control.

The great majority of the diapausing boll weevils leave the cotton fields for hibernation sites during the harvest period of late September and October. Further, the adult requires a feeding period of 1 to 3 weeks to accumulate sufficient fat reserve to attain diapause or overwintering stage. Any practice which eliminates either food or breeding sites during this critical period will be detrimental.

The most important practice during the fall to reduce populations of diapausing boll weevils is defoliation or desiccation of the cotton plants. This eliminates squares and young bolls necessary for development of the diapausing population. The next most important practice for reducing overwintering populations is to harvest the crop as quickly as possible and then destroy the stalks.

Attacking the boll weevil and pink bollworm during the fall of the year is a biologically and operationally sound practice aimed at destruction of the diapausing population. Only pink bollworms that are in diapause are able to survive the winter. This is the weakest link in its life cycle. A factor in the success of this method is that these two major cotton pests do not develop large populations on wild or alternate host plants (238). This understanding of the life cycle of an organism is necessary if the most economic level of control is desired.

Disease and Nematode Control

The principal cotton diseases and their control with cultural and other control methods are presented in Table 3.

TABLE 3 Various cotton diseases and their control by cultural and other methods. (239)

Name of Disease and Causal Organism	Control Measures
Anthracnose (the fungus *Glomeralla gossypii*). (South.) Edg.	Seed treatment; destruction of diseased plant residues; suitable crop rotations
Ascochyta, or wet weather, blight (the fungus *Ascochyta gossypii*). Syd.	Seed treatment; destruction of diseased plant residues; suitable crop rotations
Bacterial blight (the bacterium *Xanthomonas malvacearum*). (E. F. Smi.) Dows.	Seed treatment; use of resistant varieties; destruction of diseased plant residues
Fusarium with (the fungus *Fusarium oxysporum* Schlecht. f. *vasinfectum*). (Atk.) Snyder and Hansen.	Use of resistant varieties; suitable rotations; fumigation to reduce nematodes; addition of humus to soil; use of fertilizers high in potash
Root-knot (the nematode *Meloidogyne incognita*). Chitwood.	Fumigation with locally recommended fumigants; suitable crop rotations; tolerant varieties
Root rot (the fungus *Phymatotrichum omnivorum*). (Shear) Dug.	Fall plowing with phosphate additions; use of Hubam clover as cover crop; suitable crop rotations; heavy applications of organic manures in irrigated areas
Seedling diseases (several seedborne and soil-inhabiting fungi and bacteria).	Seed treatment; destruction of diseased plant residues; use of bacterial-blight resistant varieties
Verticillium wilt (the fungus *Verticillium albo-atrum*). Reinke and Berth.	Use of tolerant varieties; rotation with grain crops in irrigated areas; planting on high beds; increasing of plant population; avoiding heavy irrigation that lowers soil temperatures for prolonged periods

Source: Presley and Bird (Modified)(239)

Weed Control

Production practices which promote rapid emergence and growth of cotton tend to control weeds by shading. Crop rotation or fallowing sometimes offer another practical solution. These two practices permit the use of alternate herbicide on weeds that are difficult to control in any single crop. For example, cocklebur is very difficult to control in cotton fields but relatively easy to control in corn. Disking or plowing six to eight times during a single growing season effectively reduces the number of viable Johnson grass rhizomes present at the beginning of succeeding growing season. Plowing or disking every four weeks for two successive growing seasons has been reported to eradicate nutsedge (240).

Cultural practices tend to create adverse conditions during the pest's active or overwintering stage and result in reduced pest infestation. Expansion of such agronomic practices together with integrated control programs could reduce the use of the pesticides.

Physical and Mechanical Methods of Pest Control

Physical and mechanical methods differ from cultural methods since they are intended specifically to control the pest and are not routine agricultural practices. They may either be preventive or corrective. Their effectiveness lies in the fact that all biological species exhibit thresholds of tolerance with regard to extreme temperature, humidity, sound, physical durability and response to various regions of the electromagnetic spectrum. Among central approaches, the spectrum of radiant energy and devices such as light traps are especially promising (241,242).

Temperature is utilized in the control of soil-borne diseases caused by bacteria, viruses, fungi and nematodes (232). Fire has been found to be an effective method of control of alfalfa weevil, Hypera postica (243). In many cases stored seeds are protected by exposure to temperatures of 4 and 10 degrees C, which inactivate most grain infesting insects.

Inactivation of Plant Pathogenic Viruses by Heat in Vegetatively Propagated Plant Materials

Temperature may affect the susceptibility of host plants to virus infection, the time required for development of symptoms, and the degree of damage. The principle may be extended to those cases where the majority of all of the plants in vegetatively propagated clones are infected. A summary of viruses (Table 4 that have been inactivated in plants by heat illustrates the effectiveness of this measure (244).

TABLE 4 List of Viruses that Have Been Inactivated in Plants by Heat (244)

Virus	Plant	Treatment	Temperature (°C.)	Length of Treatment
Abutilon variegation	*Abutilon striatum*	Hot air	36	3-4 weeks
Apple mosaic	Budded seedlings	Hot air	37	28-40 days
Aster yellows	*Vinca rosea* and *Nicotiana rustica* (plants)	Hot air	38-42	2-3 weeks
	Vinca rosea (plants)	Hot water	40-45	2 1/2-24 hr.
Carnation ringspot	Carnation (plants)	Hot air	36	3-4 weeks
Cherry necrotic rusty mottle	Cherry bud sticks	Hot water	50	10 min.
Cherry ringspot	Cherry bud sticks	Hot air	100	17-24 days
Citrus tristeza	Potted plants	Hot air	95°F.±3°	121-360 days
Cranberry false blossom	Cranberry and *Vinca rosea* (plants)	Hot air	42	8 days
Cucumber mosaic	Cucumber, tobacco, *Datura stramonium* (plants)	Hot air	36	3-4 weeks
Little peach	Peach (bud sticks)	Hot water	50	3 min.
Peach red suture	Peach (bud sticks)	Hot water	50	3 min.
Peach rosette	Peach (bud sticks)	Hot water	50	8 min.
Peach X-disease (yellow-red virosis)	Peach (bud wood)	Hot water	50	6-15 min.
Peach yellows	Peach (trees)	Hot air	35	24 days
	Peach (dormant trees)	Hot water	50	10 min.
Phony peach	Peach (dormant trees)	Hot water	48	40 min.
Potato leaf roll	Potato (tubers)	Hot air	37	15-30 days
Potato witches' broom	*Vinca rosea* (plants)	Hot air	42	13 days
	Potato (tubers)	Hot air	36	6 days
Raspberry leaf mottle	Raspberry (plants)	Hot air	32-35	1-4 weeks
Raspberry leaf spot	Raspberry (plants)	Hot air	32-35	1-4 weeks
Raspberry unidentified latent virus	Raspberry (plants)	Hot air	32-35	1-4 weeks
Raspberry *Rubus* stunt	Raspberry (canes)	Hot water	45	1 1/2-2 hr.
Strawberry leaf burn or X	Strawberry (plants)	Hot air	37	7-11 days
Strawberry virus 1 (mottle)	Strawberry (plants)	Hot air	37	7-11 days
Strawberry virus 3 (crinkle)	Strawberry (plants)	Hot air	37	7-11 days
Strawberry virus 4 (vein chlorosis)	Strawberry (plants)	Hot air	37	7-11 days
Strawberry virus 2 (mild yellow edge)	Strawberry (plants)	Hot air	37	16 days
Strawberry nonpersistant viruses	Strawberry (plants)	Hot water	43-48	1/2-7 hr.

TABLE 4 (Continued)

Virus	Plant	Treatment	Temperature (°C.)	Length of Treatment
Strawberry nonpersistant viruses	Strawberry (plants)	Hot air	36-38	8-12 days
Strawberry type 2	Strawberry (plants)	Hot air	38	8 days
Strawberry viruses (unidentified)	Strawberry (plants)	Hot air	37	10 days
Sugarcane chlorotic streak	Sugarcane (cuttings)	Hot water	52	20 min.
Sugarcane ratoon stunt	Sugarcane (setts)	Hot water	50	2 hours
Sugarcane ratoon stunt	Sugarcane (cuttings)	Hot water	50	20 min.
Sugarcane sereh disease	Sugarcane (cuttings)	Hot water	52-55	30 min.
Tobacco ringspot	Tobacco (plants)	Hot air	37	3-4 weeks
Tomato aspermy	Tomato and tobacco (plants)	Hot air	36	3-4 weeks
Tomato aspermy	Chrysanthemum (plants)	Hot air	36	3-4 weeks
Tomato bushy stunt	*Datura stramonium* (plants)	Hot air	36	3-4 weeks

Source: Carter, W. (244)

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Disinfection of Plant Parasitic Nematodes by Heat

A hot water treatment, alone or together with a nematicidal dip, is used to treat plants contaminated with ectoparasitic nematodes such as *Hemicycliophora* sp. or *Criconemoides* sp. These pests are difficult to dislodge by mechanical means because their long stylets are inserted into the plant cells. Endoparasitic nematodes present within plant tissues or enclosed within the protective layers of plant parts require a penetrating chemical or physical agent to effect a kill. Heat is most commonly used. Externally applied heat is absorbed by the plant propagule and spreads within to reach the pathogens. Effective heat treatment is possible when a differential in heat susceptibility exists between plant tissue and the more sensitive nematode.

Use of Light Traps in Insect Control

Light traps employing ultraviolet or blacklight lamps are being used experimentally to determine their effectiveness for attracting moths (245). In one 113-square mile area in North Carolina 370 traps exterminated 50 to 60 percent of the adult tobacco hornworm moths in one growing season. A trap density of three per square mile in combination with stalk cuttings and insecticide treatment to prevent late season breeding of hornworms, further reduced infestation in tobacco about 80 percent. This reduction was measured in the center of the test area during the second year. Since about 20 times more males than females were captured, these results suggest the possibility of using this means to decrease mating in the field.

Other uses of black-light traps for insect control include the protection of cabbage from the attack of the cabbage looper and of celery from the celery looper (234). The deleterious effects of the European corn borer, cotton bollworm, tobacco and tomato hornworms can be minimized (234). Populations of the striped cucumber beetle and the spotted cucumber beetle were reduced and the transmission of bacterial wilt was also minimized. Light traps may reduce the need for chemical applications. Light traps may be used to attract moths and bring them into contact with chemosterilants. They can then be released. Their limitations involve need for electrical power and the presence of pests that are photosensitive. The advantages are: reduced amounts of pesticide residues on crops; they detect moth emergence and can be used for timing of control applications; attraction irrespective of the physical condition of the field; integration with other control approaches (e.g., post-season stalk cutting in tobacco (242,245) and low operating cost.

Light attraction combined with chemical attractants is a promising means of effective pest control.

Use of Resistant Varieties of Crop Plants

Plants or animals that exhibit less damage or infestation by a pest (disease, nematode or insect) than others under comparable conditions in the field are considered to be resistant. Selection and improvement results in a resistant variety which becomes an integral part of the pest management program. One of the most important contributions of agricultural programs of the pre-DDT era was the development of resistant varieties. This method of reducing pest damage has been used extensively since the turn of the century. Originally the case for natural resistance to plant pests was economic; it added nothing to the grower's cost of production. Now, pollution control is the consideration.

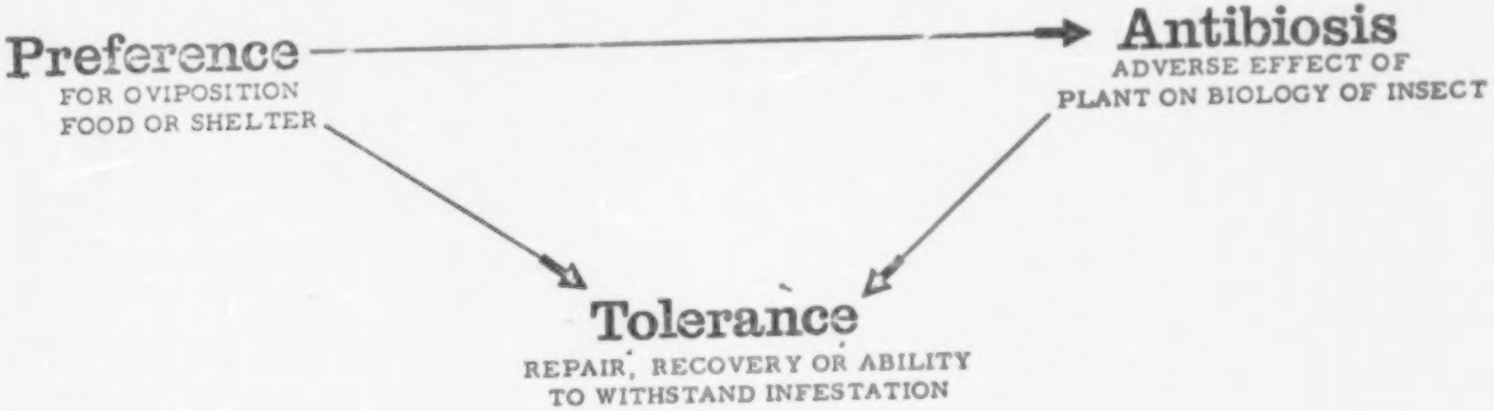
With alfalfa, small grains and tobacco, the availability of resistant varieties make the difference between profit or loss. In certain cases the resistance factor makes culture of a crop possible. Diseases such as stem rot of peanuts; rusts and smuts of cereals; anthracnose of watermelon; fusarium wilt, mosaic, black shank, and black root rot of tobacco are examples of the pathogens which are primarily controlled by resistant varieties (236). At present, approximately 75 percent of the total acreage in agriculture production in the Unites States utilizes resistant varieties (236).

Varietal resistance to insects and other pests is classified into three broad categories (Fig. 2)

A classical example of the use of the plant genetics is the control of grape phylloxera in Europe over the past 90 years. Highly resistant American varieties saved the European viticulture (247). An early search for plants resistant to insects was made in California over a period of 10 years beginning in 1881 (246). By the turn of the century, programs were underway which were directed toward increased disease resistance through breeding. Some of the better known genetic programs were concerned with mildew resistance in grapes in France; late blight of potato in several European countries; rust resistance in wheat in Australia, England and America; and, wilt resistance in flax, cotton, watermelon and cow pea in the United States. These are still being pursued actively today along with scores of others (247,248). The 1953 Yearbook of the United States Department of Agriculture listed sources of resistance in crop plants. Each year many new resistant varieties are added. Effort is being directed toward incorporating multiple pest resistance into crop varieties.

Wilt Resistance in Tobacco

A bacterial disease known as Granville became a limiting factor in flue cured tobacco producing counties in North Carolina following the turn of the century. Losses in Granville County during the period from 1920-1940, one of the key tobacco growing areas, were estimated at 30-40 million dollars.


Preference
FOR OVIPOSITION
FOOD OR SHELTER
Antibiosis
ADVERSE EFFECT OF
PLANT ON BIOLOGY OF INSECT
Tolerance
REPAIR, RECOVERY OR ABILITY
TO WITHSTAND INFESTATION

Source: Painter, R. H. (246)

Fig 2. The Nature and Categories of Plant Resistance to Pests

Intensive efforts to develop wilt-resistant tobacco were initiated in 1935 and culminated in the release in 1944 of a resistant tobacco variety of acceptable quality at a program cost of about $150,000. By 1948, the value of the tobacco in the area of Granville was estimated at $2,000,000 annually and in 1964, 416,000 acres were devoted to the tobacco crop in North Carolina and the value placed as $520,000,000. Approximately 95 percent of this acreage was planted to varieties which not only incorporated resistance to Granville wilt, but also to black shank. If resistant varieties were not available, it is estimated that yield would be reduced to less than one-fourth (248,250). No pesticides are available to economically control these diseases and protection has been obtained by cultural and biological approaches.

Varietal Resistance to Cotton Pests

Varietal resistance has been generally ignored as a possible means of controlling cotton pests until recently. Research initiated to screen available germplasm has proved to be highly rewarding.

The possibility of controlling Heliothis sp. and other lepidopterous pests by incorporating high levels of gossypol and other pigments into commercial varieties appears to be especially promising. Plants having a gossypol content of 1.5 percent or greater would cause both larval mortality and inhibition in development of Heliothis larvae.

High gossypol content is undesirable in cotton seed because of its toxicity to non-ruminant animals. A considerable amount of effort has been devoted to incorporating characteristics for low gossypol content into commercial varieties. This provides an excellent example of the necessity for a cooperative approach in developing varieties of cotton (238).

The spread of the boll weevil throughout the Cotton Belt around the start of this century brought marked changes in the type of cotton grown. The late, vigorous, long-staple upland varieties were rapidly replaced by early-maturing, short-staple types which were less susceptible to damage by the weevil because of their shorter exposure period and thicker carpel walls. These short staple types tended to be inferior in quality; and breeding efforts were directed toward increased quality and length of staple.

Knipling estimated that 75 million dollars has been expended annually for control of the boll weevil (251). In spite of this expenditure, control was far from complete and the annual loss from this insect is estimated at $200 million. Indications of the weevil developing resistance to insecticides renewed interest in the development of resistant plant types. The U.S. Cotton Boll Weevil Research Laboratory was established in 1962 at State College, Mississippi, with the objective of finding new approaches to boll weevil control or eradication with less emphasis on use of insecticides. In addition to the search for resistance, other alternative methods were also examined.

Extensive studies with cotton have demonstrated that several factors contribute significantly to differences in relative resistance and susceptibility to boll weevil attack. Some of these genetic factors are also complex and quantitative in their inheritance.

Frego bract is caused by a single recessive gene. In this mutant type, the normally adherent bracts become flared and twisted, leaving the squares relatively exposed. Studies indicate that frego types are less attractive for egg laying. In addition, the exposed squares permit ready penetration of insecticides and greater predation of the boll weevils by birds and insects. Other inherited traits, such as, red leaf and smooth leaf, contribute to reduce oviposition. Combinations between certain of these traits appear to exhibit increased nonpreference.

A large portion of the world's germ plasm of cotton has been screened at the U. S. Boll Weevil Research Laboratory, during the period 1962 to 1968. An oviposition suppression factor causing 25 to 40 percent reduction in the number of eggs laid by the weevil has been found in cotton. Research with five different genetic lines each carrying a frego gene showed a significant degree of non-preference for the oviposition to the boll weevil. Weevils were found to avoid the exposed bud for feeding and oviposition (252).

Laboratory tests have been devised which permit the screening of large numbers of plant types under controlled levels of exposure. Marked differences in oviposition scores were obtained. Inheritance studies, involving some of the less preferred versus standard types, indicated the oviposition factor to be under genetic control, but the results could not be satisfactorily interpreted on a single gene basis.

The existence of both plant attractants and repellants has been established. The attractants, still incompletely characterized, appear to be alcohols and esters, while the repellants may be terpenoids. Similarly, evidence exists for both feeding stimulants and deterrents. In neither case have the casual constituents been adequately identified.

The combination of morphological traits, oviposition factors, attractants, repellants and feeding stimulants to provide adequate field resistance in the absence of chemical control, together with the essential genetic factors for yield and fiber quality, poses a formidable task. Continued progress may be expected, however, as the intricacies are exposed (253). This is an example of a case where considerable research effort over a long period has been directed toward development of an alternative technology to pesticidal control. Results from such efforts would ultimately be the basis for reduced use of pesticides.

Control of Cyst-Nematode in Soybeans by Resistance

Discovery in 1954 of nematodes attacking soybeans in North Carolina was the first report of this pest outside the Orient (254). Damage to the crop has posed a threat to the United States soybean industry. Multiple approaches have been necessary. Application of chemicals to the soil has not been economically feasible. Crop rotation of two to three years was effective, but resulted in limited production. Federal and state quarantines were only partially successful.

In 1957, some 2,800 soybean varieties were screened for nematode resistance in heavily infested fields (254). Four varieties were found on which the nematode did not reproduce. The desirable characteristic of resistance was transferred to a commercial variety and the new combination was called Pickett. This variety was developed cooperatively by the Agricultural Research Service and the Agricultural Experiment Stations of Arkansas, Missouri, North Carolina, Tennessee, and Virginia (254).

Breeding Vegetable and Fruit Crops for Resistance to Diseases

Disease resistant vegetable varieties are especially noteworthy. By proper selection of varieties the damage caused by such destructive diseases as fusarium wilt of cabbage, tomato, and watermelon; common mosaic of beans; celery leaf blights; spinach blight; cucumber scab; and many others is reduced. In many cases, quality or productivity of the crop through use of a resistant variety is not sacrificed (255).

Examples of vegetables and fruits which have shown resistance to fungus, nematode, virus or bacterial diseases are listed in Table 5.

Disease and Insect Resistance Research for Southern Forests

The greatest forest insect resistance research is presently concentrated on the fusiform rust of southern pines by government and private agencies (256). In North Carolina, a "rust nursery" has been developed for mass screening of known seed sources of southern pines. It also permits estimation of the heritability of resistance in a natural population of southern and loblolly pine. Since 1954, a tree improvement program has been underway in Florida. This involves screening of select slash pines for resistance to fusiform rust. Selection and field testing of slash and loblolly pines of one parent and controlled progeny are being studied for their resistance.

Plant Resistance to Corn Earworm

The larvae of the bollworm is adapted to feed on a wide range of hosts and has been given common names associated with the crop attacked, e.g., the corn earworm, the cotton bollworm, and the tomato fruitworm.

Table 5 Classification of Representative Vegetable and Fruit Disease Resistance Cases According to Causal Agent, Mode of Inheritance, and Field Experience (255)

Disease	Original source of resistance	Pathogen	Field reaction
		I. Fungus Diseases	
Monogenically[a] controlled resistance			
a. Proven susceptible to races of prevalence			
1. Potato late blight	*Solanum demissum*	*Phytophthora infestans*	Immune
2. Lettuce downy mildew	European varieties	*Bremia lactucae*	Immune
3. Bean powdery mildew	Several varieties	*Erysiphe polygoni*	Immune
4. Cantaloupe powdery mildew	Indian varieties	*Erysiphe cichoracearum*	Immune
5. Bean rust	Several varieties	*Uromyces phaseoli typica*	Immune
6. Apple scab	*Malus baccata*	*Venturia inaequalis*	Immune
7. Tomato leaf mold	*Lycopersicon pimpinellifolium*	*Cladosporium fulvium*	Immune
8. Bean anthracnose	Several varieties	*Colletotrichum lindemuthianum*	Immune
b. Remaining resistant to prevalent races			
1. Spinach downy[b] mildew	Iranian variety	*Peronospora effusa*	Immune
2. Cucumber scab	Longfellow variety	*Cladosporium cucumerinum*	Immune
3. Tomato leaf sopt	*Lycopersicon hirsutum*	*Septoria lycopersici*	Resistant

Table **5** **(Continued)**

Disease	Original source of resistance	Pathogen	Field reaction
4. Tomato gray leaf spot	*L. pimpinellifolium*	*Stemphylium solani*	Immune
5. Tomato fusarium wilt	*L. pimpinellifolium*	*F. oxysporum F. lycopersici*	Immune
6. Cabbage fusarium wilt	American varieties	*F. oxysporum F. conglutianans*	Immune
7. Ceder-apple rust	Several apple varieties	*Gymnosporangium juniperivirginianae*	Immune
8. Apple scab	Asiatic species of Malus	*Venturia inaequalis*	Immune
Polygenically[a] controlled resistance			
a. Proven susceptible to races of prevalence			
1. Strawberry red stele	Aberdeen and other varieties	*Phytophthora fragariae*	Resistant
b. Remaining resistant to prevalent races			
1. Potato late blight	Selections of Solanum demissum and other species	*Phytophthora infestans*	Resistant
2. Apple scab	Antonovka	*Venturia inaequalis*	Immune
3. Cabbage fusarium wilt	American varieties	*F. oxysporum F. conglutinans*	Resistant
	II. **Nematode Diseases**		
Monogenically[a] controlled resistance			
a. Proven susceptible to races of prevalence None			
b. Remaining resistant to prevalent races			
1. Tomato root knot	*Lycopersicon peruvianum*	*Meloidogyne spp.*	Resistant
2. Pepper root knot	Santanka X S variety	*Meloidogyne spp.*	Resistant

Table 5 (Continued)

Disease	Original source of resistance	Pathogen	Field reaction'
Polygenically[a] controlled resistance			
a. Proven susceptible to races of prevalence			
None			
b. Remaining resistant to prevalent races			
1. Lima beam root know	Hopi 5989 and Westan	*Meloidogyne spp.*	Resistant
2. Peach root knot	Shalil and Yannan varieties	*Meloidogyne incognita*	Resistant
	III. Virus Diseases		
Monogenically[a] controlled resistance			
a. Proven susceptible to races of prevalence			
1. Tomato spotted wilt	Argentine variety	Spotted wilt virus	Resistant
b. Remaining resistant to prevalent races			
1. Bean mosaic	Corbett Refugee	Bean virus 1	Resistant
2. Bean pod mottle	Several varieties	Bean pod mottle virus	Immune
3. Bean southern Mosaic	Several varieties	Bean mosaic virus 4	Immune
4. Pepper mosaic	Tabasco variety	Tabasco mosaic virus	Immune
5. Spinach blight	Old Dominion; Va. Savoy	Cucumber virus 1	Immune
Polygenically[a] controlled resistance			
a. Proven susceptible to races of prevalence			
1. Tomato spotted wilt	*Lycopersicon pimpinellifolium*	Spotted wilt virus	Resistant
b. Remaining resistant to prevalent races			
1. Cabbage mosaic	Selections from varieties	Cabbage viruses A and B	Resistant

Table 5 (Continued)

Disease	Original source of resistance	Pathogen	Field reaction
2. Cucumber mosaic	Oriental varieties	Cucumber virus 1	Resistant
3. Lima bean mosaic	Fordhook and others	Cucumber virus 1	Resistant
4. Bean curly top	Several varieties	Curly top virus	Resistant
5. Potato latent mosaic	S41956 variety	Potato virus	Immune
IV. Bacterial Diseases			
Monogenically controlled resistance			
a. Proven susceptible to races of prevalence			
None			
b. Remaining resistant to prevalent races			
1. Bean halo blight	Several dry bean varieties	*Pseudomonas phaseolicola*	Resistant
Polygenically controlled resistance			
a. Proven susceptible to races of prevalence			
None			
b. Remaining resistant to prevalent races			
1. Pear fireblight	Selections from *Pyrus spp.*	*Erwinia amylovora*	Resistant

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[a] Resistances that have been found to be controlled by more than one factor pair are classified here as polygenic.

[b] In 1958, a race of *Pernospora effusa* developed extensively in California on this source of resistance.

Source: Shay, J. R.(255)

The corn earworm feeds on leaves, silks or developing grain. The most widely used control has involved chemicals. Several million pounds are being used annually. Considerable effort has been made to develop resistant corn varieties to the pest. In corn, resistance is based on chemical composition and physical characteristics.

The effect of either husk extension or husk tightness on resistance are explicable from knowledge concerning the feeding habits and cannibalistic tendencies of the earworm. Either husk extension or tightness or their combination may ensure minimizing damage to the developing grain, but have little or not effect on population dynamics, and therefore, represents a special case of tolerance rather than one of antibiosis (253). Extensive work should be undertaken to find sources of resistance (antibiosis) to leaf feeding.

Resistant varieties are one of the least expensive means of avoiding pest damage. Such efforts should not cease after a new variety is developed for a given crop. New disease strains develop for which further new resistance needs to be incorporated. Multiple pest resistance is also in need of greater study. For many crop varieties, breeders have started to look for reduced weed competition. The potential benefits of pest resistance have, as yet, not been fully exploited.

Biological Agents for Pest Control

Biological control is the suppression of the reproductive potential of organisms through the actions of parasites, predators, or pathogens to restrict pest population at a lower average density than would occur if these were absent (230).

The citrus industry in California once suffered a massive infestation of a mealy bug, cottony cushion-scale (Icerya purchasi), introduced from Australia on the gum tree in 1868. The introduction of two species of Australian ladybird provided the necessary predator-prey regulation. They first reduced the mealy bug populations to levels at which they no longer constituted a major pest infestation. Unfortunately, however, as is shown in Figure 3, cottony cushion-scale again reached major pest population levels when extensive use of DDT for citrus spraying eliminated the vedalia ladybird locally (257). Vedalia beetles had to be reintroduced to provide excellent control.

This recurrence emphasizes an inherent danger of pesticide use, i.e., a catastrophic effect on the natural regulatory mechanisms. While they temporarily diminish the numbers of a particular pest, the pesticides also reduce its natural enemies. The pest often undergoes a population explosion before enemies can recover.

Table 6 contains a list of insect parasites and predators successfully colonized in the Continental United States (269). Many of the pests listed in the table are also of economic importance in the southeastern part of the United States.

Many of the economic pests in the United States have come from other countries without their biological parasites or predators. Through lack of biological agents and abundance of food in agroecosystems some of these pests have themselves become important problems. Importation and release of biological agents have shown promise as control programs. Considerable success has also been achieved by the use of pest pathogens (bacteria, fungi and viruses) in controlling economic pests (258).

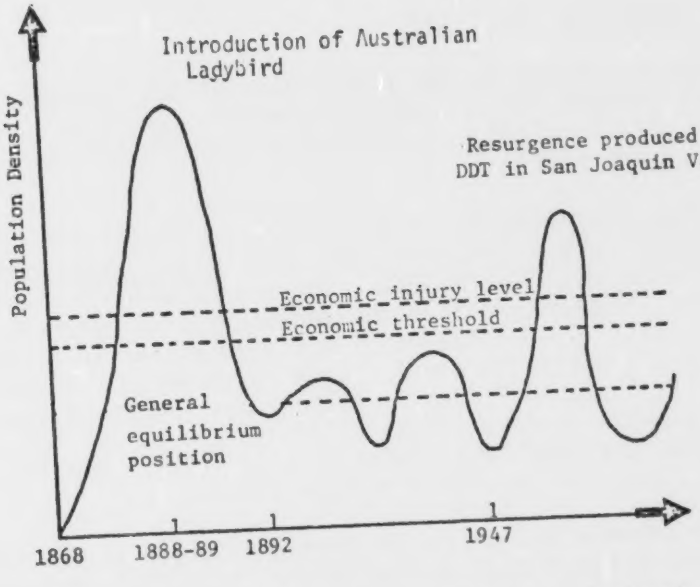

Figure 3. Cottony cushion-scale (*Icerya purchasi*) incidence on citrus in California.

Source:. Stern, V. M. et al. (257)

Table 6. Insect Pest and their Parasites and Predators Successfully Colonized in Continental United States (269)

PEST	WHERE FOUND	PARASITE OR PREDATOR
	FRUIT INSECTS	
Aphids, several species, Family Aphidae (see Field and Garden Insects)	Florida citrus and papaya areas	*Leis dimidiata 15-spilota* (Hope)
Apple mealybug, *Phenacoccus aceris* (Signoret)	Oregon, and Maine to Vermont	*Allotropa utilis* Mues.
Black scale, *Saissetia oleae* (Bern.)	California	*Aphycus helvolus* Comp. *Aphycus lounsburyi* How. *Aphycus stanleyi* (Comp.) *Coccophagus capensis* Comp. *Coccophagus cowperi* Gir. *Coccophagus pulvinariae* Comp. *Coccophagus rusti* Comp. *Coccophagus trifasciatus* Comp. *Diversinervus elegans* Silv. *Lecaniobius utilis* Comp. *Quaylea whittieri* (Gir.) *Rhizobius debilis* Blackb. *Rhizobius ventralis* (Er.) *Scutellista cyanea* Mots.
California red scale, *Aonidiella aurantii*(Mask.)	Chiefly California, Arizona, and Texas	*Aphytis lingnanensis* Comp. *Aphytis melinus* DeBach *Chilocorus kuwanae* Silv. *Comperiella fasciata* How. (red scale strain) *Cybocephalus* sp. *Habrolepis rouxi* Comp. *Lindorus lophantae* (Blaisd.) *Orcus chalybeus* (Boisd.) *Prospaltella perniciosi* Tower (red scale strain)
Citrophilus mealybug, *Pseudococcus gahani* Green (see Tree and Shrub Insects)	California	*Cleodiplosis koebelei* (Felt) *Coccophagus gurneyi* Comp. *Scymnus binaevatus* (Muls.) *Tetracnemus pretiosus* Timb.
Citrus mealybug, Pseudococcus citri (Risso) (See Tree and Shrub Insects)	California and Florida	*Allotropa citri* Mues. *Cryptolaemus montrouzieri* Muls. *Leptomastidea abnormis* (Gir.) *Pauridia peregrina* Timb.

Table 6.(Continued)

PEST	WHERE FOUND	PARASITE OR PREDATOR
	FRUIT INSECTS.--Continued.	
Coconut scale, *Aspidiotus destructor* Sign.	Florida	*Azya trinitatis* Mshll. *Cryptognatha nodiceps* Mshll.
Comstock mealybug, *Pseudococcus comstocki* (Kuw.)	Eastern apple regions	*Allotropa burrelli* Mues. *Pseudaphycus malinus* Gahan
Cottony-cushion scale, *Icerya purchasi* Mask.	California, Arizona, and Southeastern seaboard	*Cryptochaetum iceryae* (Will.) *Rodolia cardinalis* (Muls.)
Florida red scale, *Chrysomphalus aonidum* (L.)	Florida, Mississippi, Louisiana, California	*Aphytis holoxanthus* DeBach
Gypsy moth, *Porthetria dispar* (L.) (see Tree and Shrub Insects)	New England, New York, New Jersey and Pennsylvania	*Anastatus disparis* Ruschka *Apanteles melanoscelus* (Ratz.) *Blepharipa scutellata* R.-D. *Calosoma sycophanta* (L.) *Carabus auratus* L. *Compsilura concinnata* (Meig.) *Exorista larvarum* (L.) *Monodontomerus aereus* Wlkr. *Ooencyrtus kuwanai* (How.) *Parasetigena agilis* (R.-D.) *Phobocampe disparis* (Vier.)
Japanese beetle, *Popillia japonica* Newm. (See Field and Garden Insects and Tree and Shrub Insects)	The East	*Dexilla ventralis* (Ald.) *Hyperecteina aldrichi* Mesnil *Prosena siberita* (F.) *Tiphia popilliavora* Roh. *Tiphia vernalis* Roh.
Long-tailed mealybug, *Pseudococcus adonidum* (L.) (See Tree and Shrub Insects)	California	*Anagyrus fusciventris* (Gir.) *Anarhopus sydeyensis* Timb. *Tetracnemus peregrinus* Comp.
Olive scale, *Parlatoria oleae* (Colvée) (See Tree and Shrub Insects)	California and Maryland	*Aphytis maculicornis* (Masi) (Egyptian strain) (Indian strain) (Persian strain) (Spanish strain) *Aspidiotiphagus* sp. *Chilocorus bipustulatus* (L.)

Table 6. (Continued)

PEST	WHERE FOUND	PARASITE OR PREDATOR
FRUIT INSECTS.--Continued.		
Oriental fruit moth, Grapholitha molesta (Busck)	The East California, and scattered elsewhere	Agathis diversa (Mues.) Agathis festiva Mues.
Pineapple mealybug, Pseudococcus brevipes (Ckll.)	South Florida and Hawaii	Hambletonia pseudococcina Comp.
Purple scale, Lepidosaphes beckii (Newm.)	California, Florida to Texas	Aphytis lepidosaphes Comp. Physcus fulvus C. & A.
Scales, several species, Family Coccidae (see Tree and Shrub Insects)	General in fruit areas	Chilocorus sp. near distigma (Klug) Exochomus quadripustulatus (L.)
Walnut aphid, Chromaphis juglandicola (Kalt.) (see Tree and Shrub Insects)	Pacific Coast States, Utah and Idaho	Trioxys pallidus Hal.
Western grape leaf skeletonizer, Harrisina brillians B. & McD.	Southwest, Utah Colorado	Apanteles harrisinae Mues. Sturmia harrisinae Coq.
Woolly apple aphid Eriosoma lanigerum (Hausm.)	General	Aphelinus mali (Hald.) Exochomus quadripustulatus (L.)
Yellow scale, Aonidiella citrina (Coq.)	California, Texas and Florida	Comperiella bifasciata How
FIELD AND GARDEN INSECTS		
Alfalfa weevil, Hypera postica (Gyll.)	General	Anaphes pratensis (Foerst.) Bathyplectes curculionis (Thoms.) Microtonus aethiops (Nees.) Tetrastichus incertus Ratz.
Aphids, several species, Family Aphidae (see Fruit Insects)	General	
Asiatic garden beetle, Maladera castanea (Arrow)	The East	Tiphia asericae A. & J.
Clover leaf weevil Hypera punctata (F.)	General	Biolysia tristis (Grav.)

Table 6 (Continued)

PEST	WHERE FOUND	PARASITE OR PREDATOR
	FIELD AND GARDEN INSECTS.--Continued	
European corn borer, *Ostrinia nubilalis* (Hbn.)	The East and the Midwest	*Chelonus annulipes* Wesm. *Horogenes punctorius* (Roman) *Lydella thompsoni* Herting *Macrocentrus gifuensis* Ashm. *Phaeogenes nigridens* Wesm. *Sympiesis viridula* (Thoms.)
European wheat stem sawfly, *Cephus pygmaeus* (L.)	Eastern wheat areas and North Dakota	*Collyria calcitrator* (Grav.)
Greenbug, *Schizaphis graminum* (Rondani)	General	*Aphidus testaceipes* (Cresson) *Hippodamia convergens* Guer.
Hessian fly, *Phytophaga destructor* (Say)	All small-grain areas	*Pedobius metalicus* (Nees)
Imported cabbageworm, *Pieris rapae* (L.)	General	*Apanteles glomeratus* (L.)
Japanese beetle, *Popillia japonica* Newm. (see Fruit Insects and Tree and Shrub Insects)	The East	
Pea aphid, *Acyrthosiphon pisum* (Harris)	General	*Aphidus smithi* S. & A. *Hippodamia convergens* Guer.
Rhodes grass scale, *Antonina graminis* (Mask.)	Gulf States, New Mexico, Arizona and California	*Anagyrus antoninae* Timb. *Dusmetia sangwani* Rao
Spotted alfalfa aphid, *Therioaphis maculata* (Buckton)	General	*Aphelinus semiflavus* How. *Praon palitans* Mues.
Sugarcane borer, *Diatraea saccharalis* (F.)	Gulf States	*Agathis stigmatera* (Cress.) *Lixophaga diatraeae* (Tns.) *Paratheresia claripalpis* (V.d.W.)
Yellow clover aphid, *Therioaphis trifolii* (Monell)	The East	*Trioxys utilis* Mues.

Table 6. (Continued)

PEST	WHERE FOUND	PARASITE OR PREDATOR
	TREE AND SHRUB INSECTS	
Balsam woolly aphid, *Chermes piceae* Ratz.	East and West Coasts	*Aphidoletes thompsoni* Mohn. *Cremifania nigrocellulata* Cz. *Laricobius erichsonii* Rosen. *Leucopis obscura* Hal. *Scymnus impexus* Muls.
Barnacle scale, *Ceroplastes cirripediformis* Comst.	Southern coastal areas, California, and Hawaii	*Scutellista cyanea* Mots.
Birch leaf-mining sawfly, *Heterarthrus nemoratus* (Fall.)	Northern New England	*Chrysocharis laricinellae* (Ratz.) *Phanomeris phyllotomae* Mues.
Browntail moth, *Nygmia phaeorrhoea* (Donov.)	New England	*Apanteles lacteicolor* Vier *Carabus auratus* L. *Carcelia laxifrons* Vill. *Eupteromalus nidulans* (Thoms.)
Browntail moth,--Cont. *Nygmia phaeorrhoea* (Donov.)	New England	*Exorista larvarum* (L.) *Meteorus versicolor* (Wesm.) *Monodontomerus aereus* Wlkr. *Townsendicellomyia nidicola* (Tns.)
Citrophilus mealybug, *Pseudococcus gahani* Green (see Fruit Insects)	California	
Citrus mealybug, *Pseudococcus citri* (Risso) (see Fruit Insects)	California	
Elm leaf beetle, *Galerucella xanthomelaena* (Schr.)	Pacific States and the East	*Erynniopsis rondanii* Tns. *Tetrastichus brevistigma* Gahan
European earwig, *Forficula auricularia* L. (also general-nuisance pest)	Eastern Seaboard and the West	*Bigonicheta spihipennis* (Meigen)
European elm scale, *Gossyparia spuria* (Mod.)	The East and California	*Coccophagus insidiator* (Dalm.)
European pine sawfly, *Neodiprion sertifer* (Geoff.)	New England, New Jersey	*Pleoplophus basizonius* (Grav.) *Dahlbominus fuscipennis* (Zett.) *Exenterus abruptorius* (Thnb.)

Table 6 (Continued)

PEST	WHERE FOUND	PARASITE OR PREDATOR
	TREE AND SHRUB INSECTS.--Continued	
European pine shoot moth, *Rhyacionia buoliana* (Schiff.)	Northeast, North Central States, and Washington	*Temelucha interruptor* Grav. *Orgilus obscurator* (Nees) *Tetrastichus turionum* (Htg.)
European spruce sawfly, *Diprion hercyniae* (Htg.)	Upper New England	*Dahlbominus fuscipennis* (Zett.)
Gypsy moth, *Porthetria dispar* (L.) (see Fruit Insects)	New England, New York, New Jersey, and Pennsylvania	
Japanese beetle, *Popillia japonica* Newm. (see Fruit Insects and Field and Garden Insects)	The East	
Larch casebearer, *Colephora laricella* (Hbn.)	Eastern half of U.S.	*Agathis pumila* (Ratz.) *Chrysocharis laricinellae* (Ratz)
Long-tailed mealybug, *Pseudococcus adonidum* (L.) (see Fruit Insects)	Citrus-growing areas	
Nigra scale, *Saissetia nigra* (Nietn.)	California	*Aphycus helvolus* Comp.
Olive scale, *Parlatoria oleae* (Colvée) (See Fruit Insects)	California	
Oriental moth, *Cnidocampa flavescens* (Wlkr.)	Massachusetts	*Chaetexorista javana* B. & B.
Satin moth, Stilpnotia salicis (L.)	New England Washington, and Oregon	*Apanteles solitarius* (Ratz.) *Meteorus versicolor* (Wesm.)
Walnut aphid, *Chromaphis juglandicola* (Kalt.) (see Fruit Insects)	Pacific Coast States, Utah, and Idaho	

Source: Agricultural Research Service, U.S.D.A. (Modified).(269)

Insects also suffer from disease attacks. Under favorable conditions, a disease may reach epidemic proportions for an insect species. Within a few days or weeks it may reduce the species from a point of great abundance to one of scarcity. Insect diseases may be caused by protozoa, fungi, viruses and bacteria. During the last two decades an increasing awareness has developed of the great potential of insect diseases as insect control agents. About 225 species of insect viruses have now been isolated. Of these, the nuclear polyhedroses (107 species) and the granuloses (80 species) are effective candidates for insect control (259). Geer (260) reported over 300 insect viruses that can be utilized for control of specific pests.

The advantages offered by microbial pesticides are:

> Insect pathogens in general and viruses in particular, are very discriminating and infect only one species or members of closely related species (261).
>
> Microbial control is a natural method of control and increases the effectiveness naturally after once being introduced into an area. If conditions are optimum, the introduced microorganisms may spread of their own accord, resulting in widespread killing of the host.
>
> Microbial insecticides are biodegradable and may build up and remain in the soil for a long time but they are not detrimental to nontarget organisms like chemical pesticides have been.
>
> Most microbial pesticides are essentially harmless to animals and plants and may be applied in heavy doses without damaging these forms of life (258).
>
> Microbial pesticides are generally compatible with other pesticides.

Examples of pathogenic diseases associated with major economic arthropod pests are listed in Table 7. Selected examples of arthropod pathogens used successfully to control arthropod pests are presented in Table 8. Table 9 lists the arthropod pathogens commercially or experimentally produced by commercial firms for use as microbial insecticides.

TABLE 7 Examples of Pathogenic Diseases Associated with Major Economic Arthropod Pests (262)

Arthropod Pest Complex	Pathogen Genus
Forest, Ornamental and Shade Trees	
Gypsy-Tussock moth, webworm-budworm	*Aspergillus*, *Nosema*, *Thelohania*, *Bacillus*, NPV, CPV GV
Tent caterpillars	*Beauveria*, *Nosema*, *Thelohania*, *Clostridium*, *Bacillus*, NPV
Sawflies	*Beauveria*, *Entomophthora*, *Spicaria*, *Plistophora*, *Bacillus*, NPV, CPV, GV
Scolytid-beetles	*Beauveria*, *Metarrhizium*, *Spicaria*, *Brevibacterium*, *Flavobacterium*, *Nosema*
Fruits, Vegetables and Truck Crops	
Aphids-plant bugs	*Beauveria*, *Entomophthora*, *Acrostalagmus*, *Fusarium*, *Aspergillus*, *Pseudomonas*, *Vibrio*
Citrus scale-mites	*Beauveria*, *Aeschersonia*, *Cordyceps*, *Entomophthora*, *Fusarium*, *Hirsutella*, *Cephalosporium*, *Bacillus*, NIV
Cutworms-cabbageworms	*Beauveria*, *Entomophthora*, *Spicaria*, *Nosema*, *Mattesia*, *Serratia*, *Bacillus*, *Pseudomonas*, NPV, CPV, GV
Grasshoppers-crickets	*Entomophthora*, *Malameba*, *Aerobacter*, *Pseudomonas*, *Serratia*, *Rickettsiella*, NPV, NIV
Leafrollers-codling moth-budworms	*Beauveria*, *Metarrhizium*, *Aspergillus*, *Plistophora*, *Bacillus*, NPV, CPV, GV
Wireworms-grubs-chrysomelid beetles	*Beauveria*, *Metarrhizium*, *Sorosporella*, *Cordyceps*, *Bacillus*, *Clostridium*, *Streptococcus*, *Serratia*, *Rickettsiella*, *Enterella*
Grain, Grasses, Forage and Fiber Crops	
Armyworms-leafworms	*Entomophthora*, *Spicaria*, *Nosema*, *Bacillus*, NPV, CPV, GV, NIV
Bollworms-Budworms	*Beauveria*, *Spicaria*, *Nosema*, *Mattesia*, *Plistophora*, *Bacillus*, *Serratia*, NPV CPV, GV
Boll-alfalfa-clover weevils	*Beauveria*, *Hirsutella*, *Mattesia*, *Plistophora*, *Glugea*, *Bacillus*, NIV
Stem-stalk borers	*Beauveria*, *Aspergillus*, *Plistophora*, *Thelohania*, *Perezzia*, *Nosema*, NPV, NIV

TABLE 7 (Continued)

Arthropod Pest Complex	Pathogen Genus
Household, Stored Products, Man and Domesticated Animals	
Cattle grubs-flies	*Entomophthora*, *Bacillus*
Clothes moth	*Nosema*, *Bacillus*, NPV, CPV
Cockroaches-termites	*Entomophthora*, *Serratia*
Lice-mites	*Aspergillus*, *Bacillus*
Mosquitoes-midges-gnats	*Entomophthora*, *Aspergillus*, *Coelomomyces*, *Thelohania*, *Plistophora*, *Nosema*, *Bacillus*, *Enterella*, NPV
Stored products beetles	*Nosema*, *Adelina*, *Mattesia*, *Farinocystis*, *Ophyocystis*, *Bacillus*
Stored products caterpillars	*Nosema*, *Mattesia*, *Bacillus*, NPV, CPV, GV

Source: Ignoffo, C. M. (Modified) (262)

TABLE 8 Selected Examples of Arthropod Pathogens Used Successfully to Control Arthropod Pests (262)

Pathogen	Pest Species
Viruses	
Nuclear polyhedrosis	Bollworm-budworm complex
	European spruce sawfly
	Alfalfa caterpillar
	Cabbage looper
Cytoplasmic polyhedrosis	Pine processionary worm
Granulosis	Cabbageworm
	Spruce budworm
	Red-banded leaf roller
	Codling moth
Non-Inclusion	Citrus redmite
Bacteria	
Bacillus popilliae	Japanese beetle
Bacillus thuringiensis	Many caterpillar spp.
Coccobacillus acridiorum	Grasshoppers
Serratia marcescens	Termites
Protozoa	
Thelohania hyphantriae	Fall webworm
Mattesia grandis	Boll weevil
Malameba locustiae	Grasshoppers
Fungi	
Entomophthora spp.	Brown-tailed moth
	Spotted alfalfa aphid
Beauveria spp.	Chinch bug
	Colorado potato beetle
Metarrhizium anisopliae	Corn borer
	Sugar beet curculio
	Froghopper
Aeschersonia spp.	White fly and Scale insects

Source: Ignoffo, C. M. (Modified). (262)

TABLE 9. Arthropod Pathogens Commercially or Experimentally Produced by Commercial Firms for Use as Microbial Insecticides (262)

Disease Organism	Product Names[a]	Susceptible Pests
	Commercially Produced	
Bacillus popilliae	Doom, Japidemic	Japanese beetle, Scarabaeids
Bacillus thuringiensis	Agritrol, Amdol-6000, Bakthane L-69, Bactospeine, Bathurin, Biospor 2802, Biotrol BTB, Dendrobacilin, Entobakterin-3, Parasporin, Sporeine, Thuricide, Tribactur	Alfalfa caterpillar, Artichoke plume moth, Bagworm, Cabbage looper, Diamondback moth, Fruit-tree leaf roller, Grape leaf folder, Gypsy moth, Imported cabbageworm, Lawn moth, Linden looper, Oak moth, Orange dog, Rindworm complex, Saltmarsh caterpillar, Spring-Fall cankerworm, Tent caterpillar, Tobacco budworm, Tobacco budworm, Tobacco and tomato hornworm, Webworm complex, Winter moth
Heliothis NPV	Virex	Corn earworm, Cotton bollworm, Tobacco budworm, Tomato fruitworm
Trichoplusia NPV	Cabbage looper virus	Cabbage looper
Neodiprion NPV	Polyvirocide	Pine sawfly
	Experimentally Produced	
Bacillus sphaericus	IMC,*B. sphaericus*	Aquatic diptera, i.e., mosquitoes midges, simulids
Beauveria bassiana	Biotrol FBB, IMC-*B. bassiana*	Alfalfa weevil, Cockroach, Codling moth, Coconut zygaenid, Colorado potato beetle, Cutworm, European corn borer, Grasshoppers, Horsefly, Japanese beetle, Larch sawfly, Stored products beetles, Websorms
Metarrhizium anisopliae	IMC,+*M. anisopliae*	Corn borer, Cutworm Frog hopper, Leafhopper, Rhinoceros beetle, Sugar beet curculio, Sugarcane-borer, Wheat cockchafer
Nuclear Polyhedrosis Virus *Heliothis*	Biotrol VHZ:VIRON/H	Corn earworm, Cotton bollworm, Tobacco budworm, Tomato fruitworm

TABLE 9. (Continued)

Disease Organism	Product Names	Susceptible Pests
Prodenia	Biotrol VPO, VIRON/P	Cotton leafworm; Pacific, Southern, and Yellow-striped armyworm
Spodoptera	VIRON/S	Beet armyworm, Fall armyworm
Trichoplusia	Biotrol VTN; VIRON/T	Cabbage looper

[a] Only Doom, Japidemic, Biotrol BTB, and Thuricide are currently commercially available in U. S.

Source: Ignoffo, C. M. (Modified). (262)

> Perhaps the greatest single aspect not yet understood in the use of microorganisms in the control of insect pests concerns the timing of application in relation to environmental conditions. Some researchers believe that high humidity has little effect on virus diseases, others, however, have associated virus spizootics with wet weather. In the laboratory, an excess of moisture often leads to the outbreak of bacterial diseases. Low humidity is generally considered a limiting factor in fungus diseases for spore gerination, infection and subsequent sporulation of the fungus on the host. High temperature generally accelerates the course of a disease. Much remains to be learned about optimum times to apply the microorganisms.

There is a necessity of maintaining the vitality and virulence of the infecting agent especially for those microorganisms not posessing a cyst or spore stage. The possibility exists that resistant populations will develop after prolonged use of microorganisms (258) but new virulent strains of microorganisms may also be developed.

The effect that heavily applied entomogenous microorganisms may have upon plants and higher animals needs to be considered. There appears to be little likelihood, however, that microorganisms naturally pathogenic to insects could cause serious injury to animals or plants.

> A microbial insecticide can be used against one species only. Mixed formulations have not yet been widely tested.
>
> Of considerable importance is the effect that pathogenic microorganisms may have upon the insect parasites and predators of a pest. Only a few observations have been made, but enough has been learned to suggest that close attention must be paid to this relationship whenever the artificial dissemination of microorganisms is contemplated. Sometimes the insect parasites and the disease are related in a complementary or suuupementary fashion. This has been observed in alfalfa fields infested with caterpillars of the alfalfa butterfly (Colias). In fields where the polyhedral wilt disease is present but not abundant among the caterpillars, the smaller larvae may be parasitized by Apanteles while the larger larvae may be killed by the polyhedral wilt disease (258).

Herbicides are used to control aquatic weeds that obstruct water flow, increase evaporation, impair recreation and fishing and induce large losses of water through transpiration. The management of aquatic vegetation has been revitalized recently because of increased demand for fresh waters. Major aquatic weeds in the United States are water hyacinth, water fern and water lettuce and submersed weeds belonging to various genera (263, 264).

The demand for a clean environment is focusing public and legislative scrutiny on all pesticides with the possible result of curtailment of certain herbicides for use in aquatic weed control. Mechanical methods are costly, usually temporary in effect, and difficult to employ in canals. Biological control offers a potential means of control over extensive areas where the cost of chemical or mechanical practices would be prohibitive.

To date, biological control of weeds has been accomplished mainly by insects; but use of mites, snails, pathogenic microorganisms, fish, ducks and geese, manatees, and parasitic higher plants are under investigation (263). Caution is necessary for thorough screening of all animals which are introduced for control of weeds. In the absence of their preferred food they may become pests on alternate plant types

Biological Control of Red Scale and Purple Scale

Partial to complete control has been achieved using parasites in most areas in Florida. A high degree of control has also been achieved in California citrus groves using biological control organisms (265, 266, 267, 268). Table 5 contains a list of insect parasites and predators successfully colonized in the continental United States (269).

Many of the pests listed in the table are also of economic importance in the southeastern part of the United States.

Many of the economic pests in the United States have come from other countries without their biological parasites or predators. Through lack of biological agents and abundance of food in agroecosystems some of these pests have themselves become important problems. Importation and release of biological agents have shown promise as control problems. Considerable success has also been achieved by the use of pest pathogens (bacteria and virus) in controlling economic pests.

Biological Control of Cotton Bollworm and Tobacco Budworm in Mississippi

Several species of parasitic insects were reared from field collected larvae of the bollworm and the tobacco budworm in

Mississippi (270). The predominant species were two Braconids, Microplitis croceipes and Cardiochiles nigriceps. Parasites also have provided a high percent of control on cranesbill, tomato, and spider flower. Observations were reported on the effectiveness of Cardiochiles nigriceps in controlling Heliothis virescens on tobacco in areas of Florida and Georgia (271).

Control of Pea Aphid by Aphidius smithi in Kentucky

Since 1962, Aphidius smithi has been found to parasitize increasingly large numbers of the pea aphid in clover and alfalfa fields in Kentucky (272). In a 6-hour test with 60 pea aphids, parasitization by Aphidius smithi was highest (82 percent average) with first instar aphids, and lowest (0 percent) with post-productive aphids. Such differences in degree of parasitization were not found in mixed groups of various instars. Progeny production by pea aphid ceased after the fourth day if they were parasitized on the first day following birth. This parasite was propagated and widely released in California and has since become an important factor in the control of pea aphid there.

Introduced Wasps for the Control of Gypsy Moth in Alabama

Twenty-thousand parasitic wasps were released in 1971 in Russell County, Alabama, in an effort to prevent the spread of the gypsy moth (273). The wasps were shipped from New York, but are native to the Mediterranean countries. The wasps seek out egg masses of the moth and lay their eggs in the moth eggs. When the wasp eggs hatch. the larvae feed on the eggs of the moth and destroy them.

Field Control of Nantucket Pine Tip Moth by the Nematode DD-136

Field investigations have demonstrated that the nematode DD-136 will kill Nantucket pine tip moth larvae under natural conditions (274). Nematode suspensions were aided in effectiveness by addition of 10 percent glycerin and to a lesser degree by addition of wetting agents or spreader-sticker, namely 2 percent solution of Emgard 2050, Sole-Onic,CDS, and Igepon AQ-78 (274). DD-136 did not provide sufficient control of the moth to recommend its use. This case suggests that biological agents cannot be successfully employed in all situations.

Control of Bollworm (also known as corn ear worm or tomatoe fruit worm) with a Virus.

Heliothis Nuclear Polyhedral Virus, (Viron/H-TM), attacks only species of the genus Heliothis of which there are two major economic pests, H. virenscens, the tobacco budworm and H. zea, commonly known as cotton bollworm. The performance of this virus is sometimes better than commonly used chemical insecticides. It is completely specific and is absolutely safe and non-toxic. Thus virus is reasonably compatible with some chemical insecticides. The formulated form contains 126 billion inclusion bodies per ounce and a quart will control the bollworms on 10 acres of cotton with a light to moderate infestation.

Integration of the Heliothis Nuclear Polyhedrosis Virus into a Biological Control Program

A biological control program for the control of bollworm and tobacco budworm was integrated into an overwintering boll-weevil control program on cotton in the Mississippi Delta in 1965 (275). The program was designed to utilize biological control measures so that chemical control would not be required. The factors utilized in this biological program consisted of the naturally occurring predator-parasite complex and the application of the nuclear polyhedrosis virus. Heliothis control with biological agents compared favorably with a toxaphene-DDT-methyl parathion control program when virus application was initiated to coincide with hatch of egg populations.

Two-Spotted Spider Mite Control with a Fungus

A study was conducted in Alabama in 1968 to determine the importance of Entomophthora sp. as a natural control factor for filled populations of the two-spotted spider mite. Studies on the distribution of this fungus revealed its presence in 14 of the 15 counties where collections were made; the average infection rate was 25 percent (276). Five epizootics of the pathogenic fungus were observed in two-spotted spider mite populations in Lee County, Alabama. Each epizootic was characterized by a high degree of infection by Entomophthora sp. accompanied by a rapid decline in mite numbers. This was a preliminary study and no final conclusions can be drawn.

Control of Aquatic Weeds by a Snail Marisa cornuarietis

Experiments were conducted in Florida to evaluate the effectiveness of large fresh-water snails, Marisa cornuarietis, as a biological aquatic weed control agent. The snails controlled Ceratophyllum demersum, Majas quadalupensis, and Potamogeton illineonsis completely and Pistia stratiotes and Alternanthera philoxeroides partially. Marisa preferred submersed weeds to floating weeds. Little damage was done by Marisa to 4 and 5 week-old rice plants, but younger rice was killed when the snails had no other source of food (277). Except for its possible deleterious effects in rice-growing areas, Marisa was regarded as very promising for the control of aquatic weeds at least in confined bodies of water (278).

Biological Control of Alligatorweed with a Flea Beetle

Alligatorweed is an extremely prolific plant which is most difficult to control and even more difficult to kill. It does not pose a serious weed problem in South America, where 40 to 50 species of insects act as suppressing biotic agents. One of these insects, a flea beetle from the genus Agasules was introduced into the United States from Argentina. During the fall of 1965 and spring of 1966, over 9,000 beetles were transferred to selected and approved locations throughout Florida, Georgia, South Carolina and Mississippi (279). Frequent observations were made in the vicinity of the release sites and at no time was there any evidence that the beetle fed on any plant other than alligatorweed. The beetles prefer the alligatorweed that is growing in the water. The results look very promising and are being extended to pilot studies in larger areas (279).

Control of Pond Weeds by the Use of Herbivorous Fish

Common carp may control some aquatic plants by keeping the water muddy and to a lesser degree by rooting out plants. In China, Japan, Israel, and Thailand; the grass carp has been used successfully for the control of rooted aquatics (264).

Species of fish that feed upon aquatic weeds and appear promising in Alabama are listed in Table 10. Since 1957 eight species of fish have been field tested for effectiveness in aquatic weed control. In ponds, Congo tilapia, when stocked at rates of

TABLE 10 Species of fishes feeding upon filamentous algae and rooted aquatics that appear of promise in the biological control of pond weeds (263)

Common name	Scientific name	Feeding upon Filamentous algae	Feeding upon Rooted aquatics
Common carp	Cyprinis carpio (Lin.)	x	x
Grass carp	Ctenopharyagodon idellus (C. and V.)		x
Golden carp	Carassium carassius (Lin.)	x	
Goldfish	Carassius auratus Lin.	x	
Tawes	Puntius javanicus (Bleeker)	x	x
Nilem	Osteochilus hasselti (C. and V.)		x
Tilapia	Tilapia mossambica Peters	x	x
Tilapia	Tilapia melanopleura (Dum.)		x
Gourami	Osphronemus goramy (Lac.)		x
Sepat Siam	Trichogaster pectoralis (Regan)		x
Milkfish	Chanos chanos (Forskal)	x	x

Source: Swingle, H. S. (263)

Table 11 . Theoretical Population Decline in Each Subsequent Generation When a Constant Number of Sterile Males Are Released Among a Natural Population of 1 Million Females and 1 Million Males (280)

Generation	Number of virgin females in the area	Number of sterile males released each generation	Ratio of sterile to fertile males competing for each virgin female	Percentage of females mated to sterile males	Theoretical population of fertile females each subsequent generation
F1	1,000,000	2,000,000	2 : 1	66.7	333,333
F2	333,333	2,000,000	6 : 1	85.7	47,619
F3	47,619	2,000,000	42 : 1	97.7	1,107
F4	1,107	2,000,000	1,807 : 1	99.95	Less than 1

Source: Knipling, E. F. (280)

approximately 1,500 to 1,000 per acre, controlled several weed species. Grass carp controlled Chara and other plants in one month when stocked at a rate of 20 to 40 per acre. Six to 9-inch Israeli carp, when stocked at rates of 25 to 50 per acre, were effective in reducing or eliminating some pond weeds.

Sterility Approach to Insect Control

The use of insect sterilization to control and eradicate pest populations is one of the revolutionary departures of modern entomology (280-283). There are three ways by which the sterility principle might be used. One involves rearing, sterilizing by irradiation and releasing sterile members into the natural populations so that they will compete with normal ones and thereby lower the reproductive rate. A theoretical model involving such a release procedure is given in Table 11. It is assumed that the pest exists in an isolated area containing a stable population of 2 million insects with a 1:1 ratio of males to females in equilibrium with the environment and with the biotic potential canceled out by environmental resistance. Each generation, 2 million sterile males would be released in this area to compete equally for mates. By the fourth generation, the ratio of sterile to fertile males competing for each virgin female would be 1,807 to 1; with equal competition 99.95 percent of these matings would be sterile (280).

The second method utilizes chemosterilants which reduce or entirely eliminate the reproductive capacity of the pest. Chemosterilants may affect only one sex (male sterilants, female sterilant) or both sexes (male-female sterilants). Five thousand compounds have been screened and at least 200 of them produce sterility in insects. Apholate busulfan, tepa, metepa and aphxide are amont the most active chemisterilants currently under investigation (281). When administered orally or by contact these compounds produce irreversible sterility without apparent adverse effects on the mating behavior and length of life of the insects.

A third method utilizes interspecific crosses to produce sterile mates. These are then released into the pest population and produce their reduction effects.

Insects on which sterility information is available (283) and which are ready for field testing are listed in Table 12.

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TABLE 12. Insects on which sterility information is available and which are ready for field testing. (283)

Scientific Name	Common Name
Anastrepha ludens (Loew)	Mexican fruit fly
Ceratitis capitata (Wied)	Mediterranean fruit fly
Dacus cucurbitae Coq.	Melon fly
Dacus dorsalis (Hendel)	Oriental fruit fly
Anastrepha suspensa	Carribean fruit fly
Anastrepha fraterculus Wied.	South American fruit fly
Dacus tryoni (Froyg.)	Queensland fruit fly
Drosophila spp.	Vinegar flies
Dacus oleae (Gmelin)	Olive fly
Glossina morsitans (Westwood)	Tsetse fly
Glossina austeni (Newstead)	Tsetse fly
Hylemya antiqua (Meig).	Onion fly
Aedes aegypti	Yellow fever mosquito
Aedes scutellaris	Vector of filariasis (mosquito)
Culex pipiens fatigans Wied.	Vector of filariasis (mosquito)
Anopheles gambiae	Vector of malaris (mosquito)
Dermatobia hominis (Linnaeus)	Torsalo, human bot fly
Haematobia irritans (Linnaeus)	Hornfly
Musca domestica (Linnaeus)	House fly
Authonomus grandis (Bol.)	Boll weevil
Oryctes rhinoceros L.	Rhinoceros beetle
Acanthoscelides obtectus Say	Bean weevil
Melolontha vulgaris F.	Cockchafer
Carpocapsa pomonella L.	Codling moth
Diatraea saccharalis (F.)	Sugar cane borer
Leucoptera coffeella	Coffee leaf miner
Heliothio virescens (F.)	Tobacco budworm
Heliothio zeae (Boddie)	Cotton bollworm
Chilo suppressalis Walker	Rice-stem borer
Pectinophera gonypiella (Saunders)	Pink bollworm
Dysdercus peruvianus C.	Cotton red stainer
Popillia japonica (Newm.)	Japanese beetle
Protoparce sexta (Ich.)	Hornworm
Trichoplusia ni	Cabbage looper

Source: International Atomic Energy Agency (Modified). (283)

Eradication Program of the Screw Worm Fly

Screw worms were brought to the vanishing point by the release of 100 sterile males per square mile per week on Sanibel Island near Fort Myers, Florida. The eradication of the screw worms from Curacao supported the theory that screw worms could be eradicated from the southeastern states by releasing sterilized flies (282). In July of 1958, a huge sterilizing fly production facility at Sebring, Florida produced 50 million sterilized flies per week. These were distributed over all infested areas in the Southeast (Florida, Georgia, Alabama, Mississippi, South Carolina, North Carolina). By 1958, the screw worm had been eliminated from the southeastern states in which this pest can overwinter; no infestations of screw worms have since occurred (284).

The screw worms were treated with a standard dose of 7500 roentgens of gamma radiation (285). The 7500 roentgens dose was adopted as standard for eradication programs. In laboratory experiments, the radiation-induced sterility was permanent and the sterilized males were competitive with normal males in cage-mating experiments.

Further applications of the same techniques are now being tried with other pests. These are being combined with chemosterilants and genetic male sterile forms.

Eradication of the Cotton Bollworm From St. Croix, U. S. Virgin Islands

Eradication of the cotton bollworm from St. Croix, U. S. Virgin Islands, was attempted in 1968 and 1969, using the sterile-male release method (286). Both attempts failed in the primary objective of eradicating the species. The reasons were the high ratios of sterile to natural males which caused the elimination of oviposition, and the high degree of locking between the released population and the native females.

Eradication of Cotton Boll Weevil

Busulfan, a truly effective chemosterilant for the boll weevel was not discovered until recently. Prior to that time some of the aziridinyl compounds, particularly apholate, induced a rather high degree of sterility in the males, but, as might be expected, the mortality of treated insects is high and their competitiveness is reduced (287). During 1962, apholate sterilized male boll weevils, normal males and virgin untreated females were released in three experimental one acre plots of cotton in Virginia, Tennessee, and Louisiana in the ratio of 20:1:1 in each of five uniformly distributed points. The 8,850 sterile males released, over an eight week period, prevented matings between the ensuing F-1 males and females. On the seventeenth week of the experiment, no egg or feeding punctures were found in two examinations of all the squares and bolls on plants in the field. Only in the Louisiana experiment was eradication of the population achieved (208).

From June 17 through August 26, 1964, eleven weekly releases of apholate sterilized male boll weevils were made in nine cotton fields that had been treated with insecticides in the fall of 1963 to reduce diapausing weevils. An average of 8,200 males were released per acre. This release program reduced the number of oviposition punctured squares. Also, the percentage of infertile eggs, the number of live immature and adult weevils per acre in fruit, numbers of over-wintered adults and the levels of infestation during the second year were considerably lower in the release zone than in the zone treated intensively with insecticides.

Effectiveness of apholate in decreasing the sperm viability of the male boll weevil was determined (289) by allowing the weevils to feed on a diet containing from 0.001 to 0.020 percent of the chemosterilant and on plants sprayed with 0.5 and 2.5 percent solutions. After both treatments, virgin females to treated males ovipositioned eggs with decreased hatchability and emergence of progeny. At the higher levels of treatment, longevity of males was reduced. Repeated spray applications of the chemosterilant to plants especially at the higher levels, caused phytotoxicity such as leaf necrosis, stunting of growth and cessation of square production. The male boll weevil can also be sterilized with TEPA, either by feeding 1,500 ppm in the diet for two days or by an injection of 3.5 mg (290). Lower levels of TEPA produced transitory sterilization. At the effective levels, mortality was significant.

Control of House Flies with Chemosterilant Baits

Three compounds, aphoxide, aphomide, and apholate caused sterility in male and female house flies at concentrations of one percent to 0.5 percent in food given to the adults (291). Of 97 compounds administered in granulated sugar or in fly food tested in Florida, only 27 percent caused sterility in adult house flies (292).

Corn meal baits containing 0.5 percent of aphoxide (1-aziridinyl phosphine oxide), a chemosterilant, were applied on an isolated refuse dump in the Florida Keys for the control of house flies. House fly populations were reduced from 47 per grid to zero within four weeks and the percent hatch among all eggs laid was reduced to one percent within five weeks (293). House fly baits containing 0.5 percent of metepa (methaphoxide tris (2-methyl-1-aziridinyl) phosphine oxide) were applied to the droppings in a poultry house for the control of house flies. Applications were first made at weekly intervals for nine weeks, and then semi-weekly. Granular baits with corn meal as a carrier were the most effective; vermiculite granules were unsatisfactory (294).

A corn bait containing 0.75 percent of apholate was applied on a dump at Pine Island, Florida for the control of house flies. Applications were made over a week for seven consecutive weeks then five times each week for seven consecutive weeks, then five times each week for five weeks. The fly population decreased from 68 per grid to 5 to 20 during the first seven weeks and remained between 0 and 3 per grid the following five weeks (295).

Preliminary Work with Chemosterilants for Important Noctuids in Georgia

The corn earworm, the armyworm, and the granulate cutworm can be sterilized with TEPA, triethylenephosphoramide (296). Sterilization of the fall armyworm by apholate and TEPA has also been reported (297).

Insect sterility, a new technique, is offering promise for many major agricultural pests including the boll weevil, bollworm, budworm, and pink bollworm. Much research and field experimentation must be conducted on each pest problem to determine if this approach will be useful in an expanded practical control program.

Insect Attractants and Repellants

Many insects find their food, their mates and favorable sites in which to deposit their eggs by means of automatic response to various scent clues. Male moths for example, can smell potential sexual partners at a considerable distance. Each species tends to have its own distinctive odor. The survival and adaptation of many insect species depend on these odors. Frequently, they can be drawn, by means of a chemical attractant, to a trap for pest detection purposes. A toxicant that destroys them, or a substance which makes them incapable of fertile mating may also be present in the trap (298).

Attractants have been classified into three categories: sex, food, and oviposition lures. If exposure to a chemical causes a male insect to assume a mating posture, the chemical is probably a sex attractant, even if it is a synthetic and unrelated to any natural lure. Methyleugenol, the attractant for the oriental fruit fly may be a sex attractant because the chemical attracts only the male. However, it appears to be a food lure, because the flies avidly devour the chemical (299). The insect species in which female lures male and conversely, males lure or excite the females are presented in Table 13 and Table 14 respectively (300).

The use of food-based or fermenting lures have disadvantages which include a lack of specificity (traps fill with many kinds of insects), attraction over only a short distance and rapid deterioration (especially of fermenting lures). With oviposition lures, females are induced to lay their eggs on, or in the vicinity of, certain chemicals. Materials that release ammonia are known to encourage oviposition in house flies. The apple maggot is attracted to decomposing proteins, such as egg albumin (299).

Chemical attractants and associated agents, such as stimulants and assertants have been widely used for many years in studies of insect behavior. They have served many useful purposes as lures in traps, for example:

> To sample insect populations: to determine relative densities from time to time and from place to place.
>
> To trace the movement of marked insects in dispersion and migration studies.
>
> To study survival of insects in their natural environments.
>
> To study behavior associated with the search for mates and oviposition sites.

Table 13 INSECTS IN WHICH FEMALES LURE THE MALES (300)

Order	Scientific Name	Common Name
Orthoptera	*Blaberus craniifer* (Burmeister)	Giant death's head roach
	Blaberus giganteus (L.)	
	Byrsotria fumigata (Guèrin)	Cockroach
	Leucophaea maderae (F.)	Cockroach
	Mantis religiosa (L.)	Praying mantis
	Nauphoeta cinerea (Olivier)	Cockroach
	Periplaneta americana (L.)	American cockroach
	Periplaneta australasiae (Fabricius)	Australian cockroach
	Periplaneta brunnea (Burmeister)	
	Periplaneta fuliginosa (Serville)	
Lepidoptera	*Achroea grisella* (Fabricius)	Lesser wax moth
	Achroea sp.	
	Acronicta psi (L.)	
	Actias caja (L.)	Garden tiger moth
	Actias selene (Hübner)	
	Actias villica (L.)	Cream-spot tiger moth
	Agathymus baueri (Stallings & Turner)	
	Agathymus polingi (Skinner)	
	Aglia tau (L.)	Nailspot
	Agrotis fimbria (L.)	
	Agrotis ypsilon (Hufnagel)	Black cutworm
	Antheraea pernyi (Guèrin-Mèneville)	
	Antheraea (*Telea*) *polyphemus* (Cramer)	Polyphemus moth
	Aphomia gularis (Zeller)	
	Argynnis adippe (L.)	
	Argynnis euphrosyne (L.)	Pearl-bordered fritillary
	Argynnis latonia (L.)	
	Argynnis paphia (L.)	Emperor's cloak

Table 13 (Continued)

Order	Scientific Name	Common Name
Lepidopetra (Contd.)	*Autographa californica* (Speyer)	Alfalfa looper
	Bombyx mori (L.)	Silkworm moth
	Cacoecia murinana (Hb.)	
	Caligula japonica (Butler)	
	Callimorpha dominula (L.)	Scarlet tiger moth
	Callimorpha dominula persona (Hbn.)	
	Callosamia promethea (Drury)	Promethea moth
	Carpocapsa pomonella (L.)	Codling moth
	Celaena haworthii (Curtis)	Haworth's minor
	Chaerocampa elpenor (L.)	
	Clysia ambiguella (Hubner)	Grape berry moth
	Colocasia coryli (L.)	
	Colotois pennaria (L.)	
	Cossus robiniae (Pek.)	
	Cucullia argentea (Hufnagel)	Silver monk
	Cucullia verbasci (L.)	Brown monk
	Dasychira fascelina (L.)	
	Dasychira horsfieldi (Saund.)	
	Dasychira pudibunda (L.)	Pale tussock moth
	Dendrolinus pini (L.)	
	Diatrae saccharalis (F.)	Sugarcane borer
	Endromis versicolora (L.)	Kentish glory moth
	Ephestia cautella (Walker)	Almond moth
	Ephestia elutella (Hubner)	Tobacco moth
	Ephestia kühniella (Zeller)	Mediterranean flour moth
	Eumeta crameri (Westw.)	
	Euproctis chrysorrhoea (L.)	Gold tail moth
	Eupterotida fabia (Cram.)	
	Eupterotida undulata (Blanch.)	
	Galleria mellonella (L.)	Greater wax moth
	Graphotitha molesta (Busck)	Oriental fruit moth
	Harrisima brillians (B. & McD.)	Western grape leaf skeletonizer
	Heliothis virescens (F.)	Tobacco budworm

Table 13 (Continued)

Order	Scientific Name	Common Name
Lepidoptera (Contd.)	*Heliothis zea* (Boddie)	Bollworm, corn earworm, tomato fruitworm
	Heterusia cingala (Moore)	
	Hyalophora cecropia (L.)	Cecropia moth
	Hyalophora colleta	
	Hyalophora euryalus (Boisduval)	Ceanothus silk Moth
	Hypocrita jacobaeae (L.)	Cinnabar moth
	Hypogymna morio (L.)	
	Laphygma frugiperda (J. E. Smith)	Fall armyworm
	Lasiocampa quercus (L.)	Oak eggar moth
	Lasiocampa trifolii (Schiff.)	Grass eggar moth
	Lobesia (Polychrosis) *Botrana* (Schiff.)	
	Lymantria ampla (Walker)	
	Mahasena graminivora (Hampson)	Bagworm
	Malacosoma neustria (L.)	Lackey moth
	Metopsilus porcellus (L.)	
	Micropteryx spp.	
	Orgyia antiqua (L.)	Vapourer moth, rusty tussock moth
	Orgyia ericae (Germ.)	
	Orgyia gonostigma (Fabricius)	
	Parasemia plantaginis (L.)	Wood tiger moth
	Pectinophora gossypiella (Saunders)	Pink bollworm moth
	Phalera bucephala (L.)	Moonspot
	Plodia interpunctella (Hübner)	Indian meal moth
	Porthesia similis (Fuessly)	
	Porthetria (*Lymantria*) *dispar* (L.)	Gypsy moth
	Porthetria dispar japonica (Motsch)	Gypsy moth
	Porthetria (*Lymantria*) *monacha* (L.)	Nun moth

Table 13 (Continued)

Order	Scientific Name	Common Name
Lepidoptera (Contd.)	*Prodenia litura* (Fabricius)	Egyptian cotton leaf worm
	Prodenia ornithogalli (Guenée)	Yellow-striped armyworm
	Protoparce sexta (Johannson)	Tobacco hornworm
	Pierostoma palpina (L.)	Snout spinner
	Ptilophora plumigera (Schiff.)	
	Pygaera curtula (L.)	
	Pygaera pigra (Hufn.)	
	Rhyacionia buoliana (Schiff.)	Pine shoot moth
	Rhyacionia frustrana (Comstock)	Nantucket pine tip moth
	Rothschildia orizaba (Westwood)	Orizaba silk moth
	Samia cynthia (Drury)	Cynthia moth
	Sanninoidea exitosa (Say)	Peach tree borer
	Saturnia carpini (Schiff.)	
	Saturnia pavonia (L.)	Emperor moth, peacock moth
	Saturnia pavonia minor (L.)	Lesser peacock moth
	Saturnia pyri (L.)	
	Smerinthus ocellatus (L.)	Eyed hawk moth
	Solenobia fumosella (Hein.)	
	Solenobia lichenella (L.)	
	Solenobia seileri (Sauter)	
	Solenobia triquetrella (Hbn.)	
	Sphinx ligustri (L.)	Privet hawk moth
	Spilosoma lutea (Hufn.)	Buff ermine moth
	Spodoptera exigua (Hübner)	Beet armyworm
	Stilpnotia salicis (L.)	Satin moth
	Synanthedon pictipes (Grote & Robinson)	Lesser peach tree borer
	Tineola bisselliella (Hummel)	Webbing clothes moth
	Trabala vishnu (Lef.)	
	Trichoplusia ni (Hübner)	Cabbage looper

Table 13 (Continued)

Order	Scientific Name	Common Name
Lepidoptera (Contd.)	*Vanessa uritcae* (L.)	
	Zygaena filipendulae (L.)	Six-spot burnet moth
Coleoptera	*Agriotes ferrugineipennis* (LeConte)	Click beetle
	Ctenicera destructor (Brown)	Click beetle
	Ctenicera sylvatica (Van dyke)	Click beetle
	Diabrotica balteata (LeConte)	Banded cucumber beetle
	Dytiscus marginalis (L.)	
	Hemicrepidius morio (Leconte)	
	Hylecoetus dermestoides (L.)	
	Limonius californicus (Mann.)	Sugar-beet wire worm
	Limonius sp.	Wireworm
	Melolontha vulgaris (Fabricius)	
	Pachypus cornutus (Olivier)	
	Phyllophaga lanceolata (Say)	June beetle
	Rhopaea magnicornis (Blackburn)	
	Rhopaea verreauxi (Blanchard)	
	Telephorus rufa (L.)	
	Tenebrio molitor (L.)	Yellow mealworm
Hymenoptera	*Apis mellifera* (L.)	Honey bee
	Bracon hebetor (Say) (=Habrobracon juglandis)	Wasp
	Crabro cribrarius (L.)	Wasp
	Dasymutilla spp.	Velvet ant
	Diprion similis (Hartig)	Introduced pine sawfly
	Gorytes campestris (L.)	Wasp

Table 13 (Continued)

Order	Scientific Name	Common Name
Hymenoptera (Contd.)	*Gorytes mystaceus* (L.)	
	Macrocentrus ancylivora (Rohwer)	
	Macrocentrus gifuensis (Ashmead)	
	Macropis labiata (Fabricius)	
	Megarhyssa atrata (Fabricius)	
	Megarhyssa inquisitor (Say)	
	Megarhyssa lunator (L.)	
	Neodiprion lecontei (Fitch)	Red-headed pine sawfly
	Neodiprion pratti pratti (Dyar)	Virginia-pine sawfly
	Praon palitans (Muesebeck)	
	Pristiphora conjugata (Dahlb.)	Sawfly
Diptera	*Culiseta inornata* (Williston)	Mosquito
	Drosophila melanogaster (Meigen)	
	Musca domestica (L.)	House fly
	Phytophaga destructor (Say)	Hessian fly
Isoptera	*Reticulitermes arenincola* (Coellner)	Termite
	Reticulitermes flavipes (Kollar)	Eastern subterranean termite

Source: Jacobson, M. (300)

Table 14 INSECTS IN WHICH MALES LURE OR EXCITE THE FEMALES. (300)

Order	Scientific Name	Common Name
Orthoptera	Byrsotria fumigata (Guérin)	Cockroach
	Eurycotis floridana (Walker)	
	Leucophaea maderae (F.)	Cockroach
Hemiptera	Lethocerus indicus (Lepetier & Serville) (=Belostoma indica)	Giant water bug
	Rhoecocoris sulciventris (Stal.)	Bronze orange bug
Lepidoptera	Achevontia atropos (L.)	
	Achroca grisella (Fabricius)	Lesser wax moth
	Aphomia gularis (Zeller)	
	Argynnis adippe (L)	
	Argynnis aglaja (L.)	
	Argynnis paphia (L.)	Emperor's cloak
	Caligo arisbe (Hbn.)	
	Colias edusa (Fabricius)	
	Danaus plexippus (L.)	Monarch butterfly
	Elymnias undularis (Dru.)	
	Ephestia cautella (Walker)	Almond moth
	Ephestia elutella (Hübner)	Tobacco moth
	Erynnis tages (L.)	
	Eumenis semele (L.)	
	Euploca phaenareta (Schall.)	
	Euploca sp.	
	Eurytides protesilaus (L).	
	Galleria mellonella (L.)	Greater wax moth
	Hepialus behrensi (Stretch.)	
	Hepialus hectus (L.)	
	Hipparchia semele (L.)	Grayling butterfly
	Lethe rohria (F.)	
	Lycaena spp.	
	Mycalesis suaveolens (W.-M. & N.)	
	Opsiphanes invirae isagoras (Fruhst.)	
	Otosema odorata (L.)	
	Panlymnas chrysippus (L.)	
	Papilio aristolochiae (F.)	
	Pechipogon barbalis (CL.)	
	Phassus schamyl (Chr.)	
	Phlogophora meticulosa (L.)	Angleshade moth
	Pieris napi (L.)	Mustard white
	Pieris rapae (L.)	Imported cabbage worm
	Plodia interpunctella (Hübner)	Indian meal moth
	Sphinx ligustri (L.)	Privet hawk moth

Table 14 Continued.

Order	Scientific Name	Common Name
Lepidoptera (Contd.)	*Stichophthalma camadeva* (Westw.)	
	Syrichtus malvae (L.)	
	Terias hecabe fimbriata (Wall.)	
	Tineola biselliella (Hummel)	Webbing clothes moth
	Xylophasia monoglypha (Hufn.)	Dark arch moth
Coleoptera	*Anthonomus grandis* (Boheman)	Boll weevil Malachiidae bettles
Hymenoptera	*Bombus terrestris* (L.)	Bumble bee
Diptera	*Ceratitis capitata* (Wied.)	Mediterranean fruit fly
	Drosophila melanogaster (Meigen)	
	Drosophila victoria (Sturtevant)	
Mecoptera	*Harpobittacus australis* (Klug)	Scorpion fly
	Harpobittacus nigriceps (Selys)	Scorpion fly
Neuroptera	*Osmylus chrysops* (L.)	

Source: Jacobson, M. (300)

A repellent is a chemical that causes an insect to make oriented movements away from its source (234). The distance the insect need move, however, is usually much shorter than the distance it does move in response to an attractant. Ordinarily, it need only leave or avoid a treated surface or at most move a few centimeters out of the effective concentration of repellent vapor. Less use has been made of repellents for the protection of animals and plants than for the protection of man.

Ultimately the best laboratory attractants must be tested in the field where they must prove effective despite a multitude of natural odors, colors, light conditions, and weather (299; 301, 302). Examples of some potent synthetic attractants are listed in Table 15.

Use of Synthetic Attractants in Control and Eradication of the Mediterranean Fruit Fly

In 1956, the Mediterranean fruit fly (med-fly) reappeared in Florida after an absence of 26 years. Quick action by state and federal agencies (Plant Pest Control and Entomology Research Branch, U. S. Department of Agriculture) and industry, along with public support, made it possible to establish effective curtailment and eradication programs in a minimum of time. The eradication effort was a complete success (Table 16).

Lures and detection methods consisted of angelica oil, siglure and esters of cyclohexene carboxylic acid on cotton dental roll wicks with 3 percent DDVP (another phosphorus insecticide). A 25 percent lindane and 40 percent chlordane wettable powder was applied bi-weekly at 1/4 teaspoon per trap to prevent ant and spider depredation and to assist in fly kill. Traps aided in determining the effectiveness of the bait spray.

The cost of the program was 11 million dollars. Among the most important results of this research were the development:

> Of highly effective lures for use in bait traps. These served as indicators of the presence of the flies in a given location and as a measure of the progress toward eradication.
>
> Of attractive materials which could be combined with insecticides in bait sprays.

Table 15: Potent Attractants Made Synthetically.(299)

Common Name	Species Attracted	Other Species Attracted
Methyleugenol[a]	Oriental fruit fly (*Dacus dorsalis*)	*Dacus umbrosus*
Anisylacetone	Melon fly (*Dacus cucurbitae*)	Queensland fruit fly (*D. tryoni*) (*D. ocbrosiae*)
Cue-lure[a]	Melon fly (*Dacus cucurbitae*)	Queensland fruit fly (*D. tryoni*) (*D. ocbrosiae*)
	Melon fly (*Dacus cucurbitae*)	
Siglure	Mediterranean fruit fly (*Ceratitis capitata*)	Walnut husk fly (*Rhagoletis completa*)
Medlure	Mediterranean fruit fly (*Ceratitis capitata*)	
Frontalure	Southern pine beetle (*Dendroctrotonus frontalis*)	Western pine beetle (*D. brevicomis*) Douglad fir (*D. pseudotsuge*)
Trimedlure[a]	Mediterranean fluit fly (*Ceratitis capitata*)	Natal fruit fly (*Pterandrus rosa*)
Natural Disparlure	Gypsy moth (*Porthetria dispar*)	- -
Gyplure	Gypsy moth (*Porthetria dispar*)	- -
Bombykol	Silkworm worth (*Bombyx mori*)	- -
Butyl sorbate[a]	European chafer (*Amphimallon majalis*)	- -
Methyl linolenate[a]	Bark beetles (*Ips typographus*) (*Hylurgops glabratus*)	- -

Table 15. (Continued)

Common Name	Species Attracted	Other Species Attracted
Grandlure	Cotton boll weevil Anthnomous grandis Boheman	- -

[a] Most effective lure for insect under "Species Attracted" column.

Source: Beroza, M. and Green, N. (Modified) (299)

Table **16.** Status of Bait-Spray and Trap Operations for Eradication of the Mediterranean fruit fly in Florida.(303)

Date or Period Ending	Counties Being Sprayed	Acres Sprayed by Air		No. of Traps In use	Flies Per 1,000 Trap-Days
		Currently	Cumulative Coverage		
1956					
June 30	19	328,309	495,541	4,000	122,500
July 31	24	602,381	1,996,000	17,000	7,490
Aug. 31	23	239,646	3,321,091	18,100	3,780
Sept. 30	19	215,506	4,022,141	34,157	0,882
Oct. 31	16	168,485	4,921,715	39,503	0,475
Nov. 30[a]	14	106,820	5,510,613	45,060	0,161
Dec. 31[b]	14	38,055	5,787,193	45,801	0,027
1957					
Feb. 28	11	24,580	6,168,696	45,026	0,037
Apr. 30	5	11,530	6,324,529	47,810	0,051
June 30[c]	6	31,100	6,572,925	48,760	0,033
Aug. 31	2	3,500	6,723,052	36,978	0,002
Oct. 31	1	1,400	6,747,592	27,757	0,001
Dec. 31	1	4,600	6,787,653	23,722	0,004
1958					
Feb. 28	0	0	6,805,000	25,197	0

[a] Hernado (last county found infested) added.

[b] Insecticide applications completed in all eastern and southern counties.

[c] Final eradication in all counties except Hillsboro, Lake, Manatee, Orange, Pasco, Pinellas, and Polk.

Source: Steiner, L. E. et al.(303)

The bait sprays greatly suppressed house flies and mosquitoes also. Some species of tropical fish in very shallow water were susceptible to the small amounts of malathion in the bait spray. Apart from this drawback, the eradication program was very effective and relatively safe when compared to conventional aerial sprays (303).

Synthetic Pheromone of the Boll Weevil

Two terpene alcohols and two terpene aldehydes from male boll weevils, Anthonomous grandis, were isolated and identified at the Mississippi State University in 1969 (304). These compounds are the components of the pheromone to which only female boll weevils respond in laboratory tests. In bioassays, mixtures containing all four compounds elicited a response by females equivalent to or better than that elicited by males (305). Absence of either alcohols or the two aldehydes from the mixtures of synthetic compounds was identical to that obtained from corresponding mixtures of natural compounds. The extract of fecal material of boll weevils (both male and mixed sexes) produced a material highly attractive to females but not to males.

The synthesized pheromone was named grandlure. This compound, however, has a very short life, but addition of polyethylene glycol increases longevity. This stable product became a tool in surveying boll weevil infestation (306).

Virgin Female Traps for Introduced Pine Sawfly

The Pine Sawfly (Diprion similis) is a pest of eastern white pine. After it was observed that large numbers of males swarmed toward females, investigations were conducted to determine whether a sex attractant was involved. The wooden traps used consisted of a box (12 X 6 X 1 inches) with a 2 1/2-inch screened opening in the center. A virgin female was placed in the screened portion and an adhesive was spread over the wooden portion. The traps were suspended from trees in infested areas. An average of 1,000 males were attracted into each of the eight traps. Large numbers of males also fell to the ground. Some females did not attract males. The male response was rapid and many approached within 30 seconds after the traps were set. Traps set at an angle of 90 degrees to the wind direction at the edge of the woods were consistently more attractive than those set in dense woods. Greatest activity took place from midmorning to sunset. One trap with a virgin female exposed from

11 a.m. to 4 p.m. attracted more than 7,000 males. She continued attracting males at approximately 1,000 per day until she died on the fifth day, after which small numbers were caught for the next three days. Males were lured 200 feet from the forest over an open field. Chemosterilant-attractant mixtures can be effective in reducing or eradicating a field population of this insect (300).

Sex Pheromones of the Southern Pine Beetle and Other Bark Beetles

Epidemics of the southern pine beetle have occurred periodically. The control techniques consisted of cutting and spraying infested trees with benzene hexachloride (BHC) in water or oil. The trees most recently infested were cut and sprayed first. This was to interrupt the otherwise continuing aggregation of the southern pine beetle population in response to the attractants emanating from such standing, freshly attacked trees. The control effect on individual infestations appeared satisfactory but although the southern pine beetles did not aggregate on sprayed and felled timbers, their predators did. Despite very diligent and persistent efforts the BHC-control failed to affect the overall population level. The results of further research suggested that the prescribed control method was, in fact, more effective against predators, parasites and competitors of the southern pine beetle than the target insect; so BHC-control was largely abandoned in early 1969. The subsequent rapid decline of the southern pine beetle epidemic undoubtedly had a complex cause. The elimination of insecticides may account for subsequent resurgence of predators.

A method now being tried uses Frontalure 1, 5-dimethyl-6,8-dioxabicyclo (3.2.1) octane, the sex pheromone and 2 parts of d-pinene to aggregate southern pine beetle populations on the trees to be harvested and/or treated with cacodylic acid, which checked brood development but does not harm non-target insects. In fact, the simultaneous aggregation and survival of predators and competitors has become an integral part of this method.

The new method depends, like prior measures, on aerial survey detection of southern pine beetle activity. Infestations, however, can be treated immediately by the crew performing the ground check. Few tools are needed and the amount of chemicals deployed does not surpass gram quantities per acre. The reduction in labor in comparison with former control measures is considerable and environmental pollution is avoided (307).

Attractants and related agents may be used in several ways for controlling insects, as well as for gathering fundamental information about pest population, which might lead to their control. By their use in practical control programs, insects may be lured into traps and then killed by an insecticide or by adhesive, etc., or a culture of pathogens may be mixed with an attractant or feeding stimulant to destroy the pest. A chemical may also be used to attract large numbers of insects that can be sterilized and released among the native population to reduce pest numbers. Attractants are increasingly finding such uses.

Insect Hormones

One approach to the control of pests involves hormones to regulate their growth, feeding, mating, reproduction and diapause or over-wintering (302). The primary candidate is the juvenile hormone that all insects secrete at certain stages in their lives (308). The contact of a last-stage nymph, larva or pupa with a juvenile hormone induces morphogenetic damage. This results in the development of intermediates or monsters which are unable to mature and therefore die in a short time.

Subsequent investigations have revealed other important functions of the juvenile hormone in insects such as diapause, reproduction, embryogenesis, sex attractant production, and lipid metabolism (302).

The synthetic juvenile hormone analogue, trans, 10, 11-epoxy farnesenic acid methyl ester successfully terminated adult diapause in several species of Hemiptera, including the box elder bug and the red linden bug (309). Juvenile hormones are unquestionably deeply involved in the regulation of diapause and the possibility exists that more research may result in the development of antihormones which can prevent or even induce diapause.

A male pyrrhocoris treated topically with 1 mg of dichloride compound, synthetic juvenile hormone, is able to transfer enough of this chemical to females by contact during mating to induce sterility (310). This novel method of transmitting sterility should have interesting field applications if similar chemicals affecting insects other than pyrrhocoris are developed.

Williams (308) believes that synthetic juvenile hormone eventually will prove to be most effective as an egg killer (ovicide).

Echysone is another insect hormone which has the potential of becoming a selective insecticide. This substance initiates ecdysis (shedding of skin) or metamorphosis from one stage to another in the larval or nymphal development of insects. Overstimulation with ecdysone results in repeated metamorphosis without sufficient time for the accumulation of food reserves so that eventually the larva or nymph becomes exhausted and dies.

The practical utilization of these compounds becomes attractive with the realization that these hormonal effects are specific to insects (302, 308). A further advantage is that insects cannot develop immunity against these compounds.

Integrated Control

Integrated control combines several agronomic practices and pest control methods. The total effect of these combined methods is synergistic rather than additive; not only does it reduce the pesticide pollution problem, but the control obtained is more effective. Integrated control is predicated on fundamental ecological principles (311). The concept includes appropriate combinations of pesticides, natural enemies, insect pathogens, and cultural treatments, etc. (257).

The first principle emphasizes the ecosystem which includes the complex of organisms, the culture of the crop or animal and the environment. The second principle stresses economic levels. It concerns the population levels at which the pest species cause harm, damage or constitute a nuisance, and measures directed to keep them below detrimental economic levels. The third principle emphasizes the importance of avoiding disruptive actions. Measures must be designed to give adequate control in a manner which does not upset some other part of the ecosystem (312).

Integrated Control of Cotton Boll Weevil

A large scale two-year experiment is currently underway to eradicate the cotton boll weevil (251,313). The test area is 150 miles in diameter and is located around Gulfport, Mississippi and portions of Alabama and Louisiana. The cost and feasibility of eradication will be determined at the end of the study (1973) but is now estimated at 275 million dollars.

The experimental treatment involves at least six simultaneous operations. These include in season spray as needed; a series of reproduction diapause sprays in the fall to prevent overwintering; defoliation; stalk shedding and release of male boll weevils sterilized by busulfin as a final measure to reduce the remaining population to an economically acceptable level; and pheromone traps for males to prevent reproduction by surviving males. In addition, continued experiments with Frego-bract weevil resistant cotton, and temek systemic insecticide will be part of the research. The chief weapon will be diapause control by a series of up to seven fall sprays applied mainly by five helicopters in the core zone, Columbus, Mississippi, and the first buffer zone.

Properly timed, this treatment can kill up to 99 percent of weevils entering hibernation. Chemicals used will be guthion or malathion, depending upon the environmental hazard involved. Next spring, adhesive-coated traps baited with grandlure will be placed on fencelines. These traps should catch about 80 percent of emerging weevils. A single application of insecticide before square drop should kill about half of the surviving weevils, without permanently suppressing beneficial insect populations. The sterile males will then be released at 50 to 200 per acre for several generations, and theoretically should reduce the native population by 97 percent in each generation (251, 313). The reduction of the boll weevil problem to an economically acceptable level would be an important contribution toward the goal of reducing environmental pollution caused by the use of broad spectrum insecticides.

Integrated Control of *Heliothis sp.*

Relatively little is known about the numerical relationship between parasites and their hosts. However, it seems to be within the realm of feasibility to mass produce and release sufficient selective parasites to truly manage some insect populations. This system of insect population management should have its maximum efficiency when the host insect population is high and should have diminished efficiency when it is low. This is just the reverse of the potential efficiency of the genetic approach. Therefore, the parasite release technique and the genetic technique may eventually prove to be highly complementary when they are integrated into one system of suppression (251). Insect pathologists are making considerable progress in developing microbial agents which may further strengthen the integrated approach.

Integrated Control System for Hornworms on Tobacco

Control of hornworms on tobacco with insecticides is not completely satisfactory. When *Polistes* wasps were induced to nest in shelters erected around the field, populations of fifth instar hornworms were reduced by about 60 percent and damaged by 76 percent. One-fifth the recommended rate of the insecticides TDE or endrin, applied as top sprays, gave reliable and adequate control of both hornworms and budworms (314).

Integrated Biological and Chemical Control of Aquatic Weeds

The introduction of the beetle (Agasicles sp.) as a biological control agent has been an added deterrent to the growth of alligatorweed. Alligatorweed may be controlled with less herbicide in the presence of large populations of alligatorweed flea beetles. The beetles showed a feeding preference for young regrowth over more mature untreated alligatorweed and maintained sufficient feeding pressure to eliminate the floating mat growth (315).

Integrated control programs in general require a higher level of scientific background when compared to chemical control. Information is usually needed regarding the following points: the general biology, distribution and behavior of the key pests; an approximation of the pest population levels that can be tolerated without significant crop loss; a rough evaluation of the times, places of occurrence, and the significance of the major predators, parasites, and pathogens present; information on the impact of the use of pesticides, insecticides, herbicides, and fungicides, as well as other control measures on natural enemies, the agroecosystems and the natural system.

Miscellaneous Methods

Seed Laws

One of the methods by which weeds spread is through their inclusion with crop seeds. The federal seed act (316) requires in part that the following information be provided on seed levels in interstate commerce: percentage of pure seed of the named crop, percentage of other crop seeds, percentage of weed seeds, and the rate of their occurrence. Crop seeds cannot be sold for seeding purposes in most states if they contain noxious weed seeds in excess of a specified percent by weight, generally two or three percent. Seed laws at state and federal levels have been important in reducing the spread of weed species, in improving seed quality (317), and in reducing the quantities of herbicides needed for control.

Seed Certification

Seed certification is the system used to keep pedigree records for crop varieties and to make available sources of genetically pure, disease and relatively weed free seeds and propagating material for general distribution. Without such a system, seeds tend to become contaminated and mixed and lose identity.

Only about five percent of seeds used by farmers are certified. They contain 1.2 weed seeds per pound, in comparison with 160 weed seeds per pound for non-certified seeds. Although seed certification programs have direct control over only a small percentage of the small grain that is planted, their beneficial effect on quality of seeds planted by farmers will grow through continuing seed certification and educational program (318, 233).

Quarantine and Regulatory Controls

Quarantine refers to the restraints or restrictions placed upon the transportation of animals, livestock, poultry, plants, fruits and vegetables, plant and animal products or other materials which are suspected of being carriers of agricultural pests. Such precautions are necessary because many of the worst plant pests have come from other countries and thrived here because of abundant food and few natural enemies. The quarantine system is a necessary element of the overall national preventive pest control programs (317) and contributes to the reduced needs for pest control by chemical or other methods.

Publicly supported regulatory programs are an essential part of the overall effort to protect crops and livestock from pests. Various methods are used in eradication, containment and suppression programs; these include chemical, cultural and biological measures. Greater merit is indicated for large scale alternative control programs as compared to region-wide chemical spraying. Many more of the alternative techniques of pest control are employed on larger areas than on individual farms. Programs of state and federal agencies, in cooperation with private agencies, and, citizens, will be required in pest control.

Pest Surveillance

The detection of pests and surveys of their distribution and abundance are essential prerequisites to rational control programs. The first principle of pest detection and surveys in its relationship to control is that no control measures should be undertaken against a pest unless that pest is actually present. In many instances, this principle is not followed. This is partly attributed to the lack of appreciation of the merits of pest assessment. The second principle of pest detection is that no control measures should be undertaken unless it is known that the pest is present in sufficient numbers to cause economic loss. In order to achieve these basic principles insect scouting programs have been initiated in a few states.

In 1971, cotton insect scouting programs were conducted in ten states (Alabama, Arkansas, Georgia, Mississippi, Missouri, North Carolina, South Carolina, Texas and Louisiana) on 877,225 acres out of 10,421,000 acres under cultivation. A scout who has received special training by an extension service entomologist can keep growers informed of the following (319):

> When the infestation count is large enough to warrant starting a control program
>
> When to expect hatchout of boll weevils or bollworms
>
> How long to continue the control program into the fall

It is estimated that a considerable number of unnecessary pesticide applications can be avoided without loss in economic returns. Sufficient understanding of pest ecology and biology exists so that such programs can be initiated now.

Genetic Manipulations

The first attempt at control by the application of genetics to decrease fitness involved the tsetse flies. Interspecific crosses were made of *Glossina Swynnertoni* and the reproductively but not sexually isolate *G. morsitans*. Viable but sterile offspring were obtained from such crosses, which competed with normal individuals for survival in the environment (283).

Many lethal genes, existing in populations of insect species, have been subjected to genetic analyses. Deleterious genes need not be lethal or act immediately for effective control. Drastic reductions in insect numbers can be obtained theoretically by constant low-level mortality factors superimposed on populations already exposed to the stress of adverse environmental conditions, i.e., low temperature during hibernation. Three requirements are essential to the success of control measures utilizing the release of strains carrying unfavorable genetic characters: the factors must not prevent rearing under laboratory conditions; they must not interfere with mating ability; and they should act at particular times, such as during hibernation or immature stages. It has been postulated on theoretical grounds that the eradication of the boll weevil could be achieved in a few years if males carrying two lethal genes were repeatedly released into field populations.

Although genetic methods seem to offer promising leads, considerable work is needed before such techniques can be incorporated at a practical level.

Development of Safer Pesticides

Although alternative pest control technology exists, conventional chemicals will remain the chief means of insect pest control for the foreseeable future (251, 312, 320, 321). An explanation for this lag in the use of alternative methods merits explanation. A growing concern has existed over certain known and potential threats to the quality of the environment because of the use of the broad-spectrum pesticides. This concern however, has not been fully translated into increased commitment of resources toward searching for development of or large-scale testing of alternative methods. The United States must be prepared to support substantially larger expenditures from its resources for utilizing and broadening the knowledge of alternative pest control technology and development of safter pesticides if there is to be great progress in correcting or alleviating many pesticidal pollution problems. Several years will be required to perfect these techniques prior to use at a national or regional level.

Most of the chemicals widely used for agricultural pest control have been selected on the basis of optimum effectiveness against the pest and for maximum persistence. The original DDT patent of 1939 covered a number of insecticidal analogs (321). These included methoxychlor, ethoxychlor and methychlor. All of these are relatively inexpensive persistent insecticides effective against a wide spectrum of insect pests. However, DDT is the most stable and has had extensive use, whereas methoxychlor has been used on a modest scale, and ethoxychlor and methylchlor not at all. These DDT-related compounds are rapidly degraded by the multifunction oxidases of higher animals and converted to water soluble compounds; DDT is not. Similarly, the related compounds are less toxic to fish than DDT. Ethoxychlor, methychlor and other biodegradable derivatives of DDT merit further investigation as replacements for DDT and other persistent and non-biodegradable chlorinated hydrocarbons. Similar safer analogs (fenthion, ronnel, dicapthon) exist for methyl parathion, one of the most commonly used organic phosphate insecticide (321). Further consideration should also be directed toward the effect of these pesticides on the natural enemies of pests.

If pesticide chemicals are to be used harmoniously with the environment and the agroecosystem then materials that are inherently selective must be employed. All pesticides have some selectivity but the range is not very great. Much effort has been expended in seeking materials with relatively high toxicity to invertebrates and low toxicity to mammals. Differential toxicity within the arthropods (insects) should be sought. The ultimate in specificity that would permit prescribing a specific chemical for each pest species would be ideal but is not needed. However, materials are needed that are specific for groups of pests such as aphids, grasshoppers, lepidopterous larvae, weevils, and so forth.

There are indications that safer chemicals can be synthesized (322). Somehow, the imperative need to replace obsolescent agents with substances having more desirable properties has not been sufficiently encouraged.

Through greater cooperation between public and private sectors and by legislation of adequate laws, excessive reliance on broad spectrum pesticides can be reduced. Creation of a situation where voluntary information and resource exchange exists can solve the problem of erratic and short term pesticidal control. As with other pollution problems, solution of the pesticidal dilemma will require a national commitment.

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PESTICIDE STUDY CONTRACTS

Project Title	Contractor
1. Agricultural Croplands Southeastern United States	Teledyne, Brown Engineering Research Park, Huntsville, Alabama 35807
2. Movement and Impact of Pesticides Used in Forest Management on the Aquatic Environment and Ecosystem, Forest and Aquatic Environments, Northeastern United States	Cornell Aeronautical Laboratory, Inc. P. O. Box 235, Buffalo, New York 14221
3. The Effects of Agricultural Pesticides in the Aquatic Environment, Irrigated Croplands, San Joaquin Valley, Western United States	University of California, Food Protection and Toxicology Center, Davis, California 95616
4. Total Effect of Pesticides in the Environment, Non-Irrigated Croplands	Ryckman, Edgerley, Tomlinson & Associates, Inc. 500 Coronet Bldg., 225 So. Meramec Ave., St. Louis, Mo. 63105
5. Total Effect of Suburban Use of Pesticides in Homes and Gardens	Ryckman, Edgerley, Tomlinson & Associates, Inc. 500 Coronet Bldg., 225 So. Meramec Ave., St. Louis, Mo. 63105
6. Pollution Potential in Manufacturing	Midwest Research Institute, 425 Volker Boulevard Kansas City, Mo., 64110 Area Code 816 561-0202
7. The Use and Effects of Pesticides for Rangeland Sagebrush Control, Western United States	Midwest Research Institute, 425 Volker Boulevard Kansas City, Mo., 64110 Area Code 816 561-0202
8. Catalog of Pesticides Research Projects	Smithsonian Science Information Exchange, Inc. 1730 M Street, N. W., Washington, D. C. 20036
9. Environmental Effects of Pesticides Used for Vector Control in Northeastern United States	Arthur D. Little Inc., Acorn Park Cambridge, Massachusetts 02140

Interagency Agreements:

U. S. Department of Agriculture - Economic Research Service
U. S. Department of Agriculture - Agricultural Research Service

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